SPLENDORS OF THE SKY

ISABEL M. LEWIS

THE 26-INCH EQUATORIAL OF THE UNITED STATES NAVAL OBSERVATORY WITH WHICH THE SATELLITES OF MARS WERE DISCOVERED IN 1877

Splendours of the Sky

BY

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PREFACE

THE following book has been compiled from a series of articles written by the author during the past three years for "The New York Evening Sun" upon astronomical subjects of general, popular interests.

Requests from a number of readers for copies of these articles have led to the publication of a selection and arrangement of them, including some revisions and changes, which form a connected and comprehensive treatment of the astronomy of the present day.

Diagrams, formulæ and mathematical proofs have been entirely omitted as unsuitable to a popular treatment of the subject. It is not the desire of the author to attempt to enter into a detailed scientific exposition of astronomical truths but simply to tell in non-technical terms something about the wonderful progress the astronomers are now making in delving into the mysteries of time and space and in solving problems concerning the heavenly bodies that a few years ago appeared to be beyond solution.

CHAPTER I

VASSALS OF THE SUN

WHO has not admired the brilliant and beautiful planets, members of our own solar system—glorious Venus, fiery Mars, ringed Saturn and magnificent Jupiter? Possibly some of us have also spied in the twilight hour following sunset or preceding sunrise elusive Mercury, closest attendant of the sun.

From remotest antiquity these five planets have been observed apparently wandering among the fixed stars, though in truth separated from them by inconceivable immensities of space. Eight planets in all, including our own little planet earth, with their attendant moons, unceasingly encircle the sun in obedience to the universal and mysterious law of gravitation. To modern astronomers we owe the discovery of the two outermost planets,

Uranus, just at the limit of visibility of the unaided eye, and Neptune, barely showing in small telescopes the planetary disk that distinguishes it from the fixed stars far beyond.

Of the nearer planets, Mercury is by far the most difficult to observe, for it is lost in the solar rays most of the time. In less than three months, eighty-eight days to be exact, Mercury completes one trip around the sun. During a considerable portion of this time the planet is either hidden behind the sun or passing between us and the sun. It is only when farthest to the east or west of the sun, at elongations, that it is observable. As Mercury can never depart more than twenty-eight degrees from the sun, even under the most favorable circumstances, it usually escapes detection. At eastern elongations Mercury sets after the sun and is evening star. At western elongations it may be seen in the twilight hours just preceding sunrise as morning star, and when found delights us by appearing as a beautiful star about as bright as brilliant Vega. Mercury is the nearest to the sun of all the planets, also the smallest, the hottest and the fleetest. Its orbit departs more from the circular shape than does the orbit of any other planet, so that

the planet's distance from the sun varies as much as fifteen million miles. The diameter of Mercury is only three thousand miles and both Jupiter and Saturn have satellites that surpass Mercury in size. It is almost a certainty that Mercury always turns the same face toward the sun. The temperature, therefore, is torrid on one side, frigid on the other, and the temperature differences are made all the more extreme from the fact that Mercury has no atmosphere, probably, as is the case with the moon, because it has not sufficient gravitational force to hold one.

In Venus we behold our sister planet. The diameter of this planet is about two hundred miles less than that of our own planet. Venus far surpasses all the other planets in brilliancy, even Jupiter, the giant among them all, cannot rival her in splendor. This is due to the fact that she is nearer to us than any other planet, at nearest approach only 26,000,000 miles away. In strong contrast to Mercury, Venus is surrounded by a dense atmosphere. The surface of the planet is hidden by clouds and no surface markings can be distinguished with certainty, and so it is still undecided whether Venus rotates on its axis in a day about

equal in length to our own day or turns the same face toward the sun. Most astronomers now incline to the belief that the same face is always toward the sun. Even were the latter the true condition, Venus would not have the extremes of temperature found upon Mercury, partly because its distance from the sun is much greater and partly because of its dense atmosphere. Winds of such intensity as we never experience upon the earth would constantly pass between the hot and cold sides of the planet, tending to equalize the great extremes of temperature existing upon the two sides.

Mercury and Venus, as far as we know, are unattended by satellites and are the only two planets in the solar system of which this is true. Since they have orbits lying between the earth and the sun they also have phases similar to those of the moon. Venus never can be seen more than forty-seven degrees from the sun and so is either morning or evening star. She can never be seen overhead in the evening, but always appears in the eastern or western skies, in early morning hours in the east, preceding sunrise, or in early evening hours in the west, following sunset.

Mars, the small world that has aroused so much controversy because of its peculiar surface markings, lies next beyond the earth as we pass outward from the sun. Its diameter is somewhat more than half and its surface area less than one-third that of the earth. Its green and reddish patches, its snow caps and its much-talked-of "canals" have interested even those most indifferent to the mysteries of the heavens. Mars is the last of the terrestrial or inner group of planets, Mercury, Venus, Earth and Mars, as distinguished from the major planets, Jupiter, Saturn, Uranus and Neptune.

The orbit of Mars, which is 142,000,000 miles from the sun, is separated from the orbit of Jupiter by a vast expanse of 350,000,000 miles. In this immense zone are found the orbits of the asteroids or planetoids, mere fragments of planetary matter that in no case possess a diameter greater than 500 miles. To find names for the members of this numerous group and keep track of their movements is becoming a burdensome task for the astronomer. They are now numbered by hundreds. It was once believed they were fragments of a shattered planet, but it is now thought they are rather the material for a planet that was

never allowed to take form, due to the disruptive effect of Jupiter's mighty mass.

The major planets are distinguished from the terrestrial group by their great size, enormous distances from the sun and extremely low density, not much exceeding that of water—in the case of Saturn even less. The density of the terrestrial group is extremely high. Our own planet, which possesses the highest density of all the planets, has 5.5 times the density of water.

This low density of the outer planets implies they are still mostly in a gaseous condition.

Jupiter, the largest of the planets, has a mass two and one half times as great as all the other planets combined. He is also the centre of a large satellite system of nine moons, two of which surpass the planet Mercury in size. Four of these moons have been known from the days of Galileo and can be observed even with an opera glass.

Saturn, next beyond Jupiter, is noted for its wonderful system of concentric rings, composed of countless tiny moonlets, and its large satellite family of nine moons. Titan, the largest, has a diameter of 3,500 miles, which places it between Mercury and Mars in size. Saturn is also remarkable

for the fact that its density is less than water. It is the only planet in the solar systems that would float in water.

It is almost impossible for the human mind to grasp the immensity of this solar system of ours and realize as well that even the solar system is but one of millions of systems that form the stellar universe.

If we should try to represent our solar system to scale and should choose for the sun a globe two and a half feet in diameter, Jupiter would be a ball three inches in diameter. Saturn would be a little over two and a half inches in diameter, Uranus and Neptune balls of nearly equal size, a little more than one inch in diameter, Uranus exceeding Neptune in diameter by about one-tenth of an inch, while the terrestrial group would appear insignificant beside these larger members of our system. Venus and our own Earth on this scale would be but one-quarter of an inch in diameter, while Mars and Mercury would have diameters one-seventh and one-tenth of an inch respectively. Placed at the distance of the nearest star our largest telescopes would fail to reveal the existence of Jupiter, the largest of all the planets.

To form some idea of the relative distances of the planets from the sun, let us consider the time that it takes a ray of sunlight to reach each of the planetary orbits travelling outward from the sun at a speed of 186,000 miles per second. Three minutes after leaving the sun it crosses the orbit of Mercury, at the end of six minutes it passes the orbit of Venus, eight and a fraction minutes it requires to reach the earth's orbit, and nearly thirteen minutes after leaving the sun it arrives at the orbit of Mars. Darting into the vast abyss lying beyond Mars' orbit, it travels fully thirty minutes longer before it comes to the orbit of Jupiter. Thirty-six more minutes pass before it comes to Saturn's orbit. It takes more than two and a half hours for this ray of sunlight to travel from the sun to the orbit of Uranus. More than four hours after the time it started it finally comes to the orbit of Neptune at a distance of nearly 2,800,000,000 miles from the sun. From here it speeds onward to the stars beyond and reaches the nearest in four and a half years.

The periods of revolution of the planets around the sun differ as widely as their masses and distances from the sun. In eighty-eight days Mer-

cury completes its rapid journey. Venus requires seven and one-half months, Mars six hundred and eighty-seven days. Twelve years pass by, however, before Jupiter makes one trip around the sun. Saturn requires twenty-nine and one-half years, Uranus eighty-four years, and nearly one hundred and sixty-five years elapse before Neptune sweeps entirely around his mighty path through the heavens.

CHAPTER II

THE ORIGIN OF THE SOLAR SYSTEM

THAT the material of which the sun and planets are fashioned originally existed in the form of a nebulous mass practically all astronomers believe; but the process by which our solar system developed from a chaotic nebula into an orderly and well-regulated family of planets revolving around a central sun is one of the fascinating and puzzling problems of astronomy.

Near the end of the eighteenth century the famous mathematician and astronomer La Place, advanced his noted nebular hypothesis of the origin of the solar system which gained universal acceptance almost immediately and held undisputed sway for nearly an entire century. Modifications and changes had to be made at times, however, to adapt the theory to later discoveries, and finally in

the light of more recent researches an almost complete abandonment of the theory has resulted.

According to the nebular hypothesis, a vast gaseous nebula originally extended beyond the present orbit of the outermost planet, Neptune, and slowly rotated in the direction in which the planets now revolve around the sun. Such a great mass would lose heat by radiation into space and would contract. As the rotating mass contracted it would of necessity rotate faster and faster, and as a result equatorial rings of nebulous matter would be abandoned, which would have a tendency to break unless perfectly uniform and circular. Excess of material at any one point in the ring would draw to itself the remaining material in the ring. The result would be the formation of a planet which would continue to revolve around the central contracting nebula at the distance at which the ring was abandoned. Other rings left behind at various stages as the central nebulous mass continued to contract, would form additional planets. The globular masses formed when the abandoned rings broke up might, in the same manner, contract and leave behind rings which would go to form the satellites by which most of the planets are at-

tended. The rings of Saturn were supposed to be rings abandoned by the contracting mass of that planet, which, for some reason, had kept their original form. The earth, according to the nebular hypothesis, was once in a gaseous condition and gradually cooled down to its present form of surface crust and molten interior. The theory of La Place was in accord with all the facts then known concerning the solar system. It seemed to explain satisfactorily why the planets move in orbits that are almost perfect circles and why they all turn on their axes and revolve around the sun in the same direction, namely from west to east, and also why they all revolve around the sun in nearly the same plane.

The asteroids or planetoids, however, furnish notable exceptions to these laws. At the time La Place advanced his theory they had not been discovered. These small members of our systems are now numbered by hundreds. The diameter of the largest does not exceed five hundred miles, and most of them are much smaller. Their orbits lie between the orbits of Mars and Jupiter and are remarkably different from the orbits of the major planets, for they vary in shape from almost per-

fect circles to ellipses as elongated as some cometary orbits. Instead of lying in nearly the same plane as is the case with the major planets, they intersect the common plane at all angles from zero to thirty-five degrees, and could, therefore, never have been formed from an abandoned ring of the contracting solar nebula.

Moreover, it has been discovered that certain satellites of the outer planets do not share the common direction of revolution of the planets from west to east, but move in a retrograde motion around their primaries from east to west. Also, according to the nebular hypothesis, no satellite could revolve around its primary in less time than its primary takes to turn on its axis; but Phobos, the inner satellite of Mars, finishes three revolutions and starts on a fourth before Mars has turned once on its axis. The moonlets composing the inner ring of Saturn also complete circuits in between five and six hours, although Saturn requires ten and a half hours to rotate on its axis. Other instances might be cited to show the failure of the nebular hypothesis to explain all the facts now known concerning our solar system. This noted hypothesis served as a good working hypothesis in

its day, nevertheless, and greatly stimulated investigations in the allied sciences of geology, zoology and biology in the nineteenth century. It is far easier to tear down a theory than to build up a new one that will fit in with all the observed facts. Several new theories of the origin of the solar system have been advanced, but no one theory seems satisfactory in all respects. Astronomical discoveries of recent years have shown our solar system to be a more complicated mechanism than was at first suspected.

The idea that the nebula from which the solar system was evolved was originally spiral in form is now quite generally held. Chamberlin and Moulton have developed a theory of the origin of the solar system along these lines, known as the Planetesimal Theory. It can be shown that a spiral nebula might arise through the close approach of two stars, or from the approach of two nebulous streams and their curling together by mutual attraction, or by the curling up of a single nebulous stream, due to its own gravitation. There are probably close to two billion luminous stars in our stellar system, all in motion, and we can reasonably assume that collisions or close approaches will oc-

cur despite the fact that enormous distances separate the stars from one another. When we admit, as actual discovery forces us to, the existence of dark stars and dark star systems and dark nebulous matter, as well as bright, the likelihood of occasional collisions or close approaches increases. It has also been found that the nebula from which a solar system evolves need not necessarily be gaseous or at high temperature, since a nebulous swarm of meteoric particles would act in the same way as the molecules of gas in a gaseous nebula.

In favor of the belief that the original solar nebula was spiral in form, it can be shown that, while no nebula of the form required by the nebular hypothesis of La Place is known to exist, the spiral form of nebula abounds throughout the universe. Even the stellar universe itself may consist of stars streaming in obedience to the laws governing a spiral formation. Although we are still uncertain as to the exact manner of the evolution of our solar system from the primitive nebula, proofs of the fact that suns evolve from nebulæ and pass through all the stages from youth to old age are written in the heavens themselves. A careful survey of the heavens shows stars not yet freed of

their nebulous appendages, and even whole clusters of stars wrapped in nebulous matter. All stages of evolution are represented from the blue stars of youth to the feebly flickering red stars of old age and the cold, dark stars that have lived their lives and speed onward through space until the time comes, when they may start perchance, upon a new life, through some celestial catastrophe.

CHAPTER III

EVASIVE MERCURY

MERCURY is the most difficult to observe of all the satellites of the sun, because it never departs more than twenty-eight degrees from its ruler, even under the most favorable circumstances, and is usually entirely concealed by the blinding rays of the sun.

Spring is the best time to view this planet as evening star, and autumn the most favorable time to search for it as morning star, since the ecliptic, the path of the sun, near which the moon and the planets are always to be found, then rises most sharply along the horizon.

Mercury can only be seen for about two weeks at a time near the dates of its elongations. The planet is, of course, found with great difficulty in high latitudes and is rarely seen in northern Europe.

In fact, comparatively few people have ever seen this closest attendant of the sun. Copernicus, so we are told, never saw it.

When seen at time of elongation, near the horizon, Mercury usually has a slightly reddish tinge, due to the fact that its rays are travelling through the denser lower strata of the atmosphere. It will also appear to twinkle somewhat for the same reason. Mercury is, in fact, sometimes referred to as "the twinkler."

All the other planets shine with calm, steady light, and it is interesting to compare Mercury, if it can be found, with the other bright planets when they are visible at the same time.

Most astronomical observations of Mercury are made in full daylight by screening off the light of the sun. Sunlight is less disturbing to observations made with large telescopes than the dense haze of sunset and sunrise skies. It is due largely to the difficulties of observing this planet that the period of its rotation on its axis and, therefore, the length of its day and night has not been settled beyond question.

It is virtually certain, though, that the planet's rotation period is equal to the period of its revolu-

tion around the sun, or eighty-eight days, and that it always keeps the same face turned toward the sun. If this is the case there are two longitudinal zones on the planet's surface forty-seven degrees in width that experience a rising and setting of the sun and have forty-four days of light, followed by an equal period of darkness. This is due to the great ellipticity of the planet's orbit, which departs more from a circular form than that of any other planet in the solar system.

The planet's rate of rotation on its axis is uniform, but its rate of revolution around the sun, due to the high eccentricity of its orbit, varies from thirty-six miles a second at perihelion to twenty-three miles a second at aphelion. So there are times when Mercury falls behind its mean position by as much as twenty-three and one-half degrees, and times when it darts ahead of its mean position by an equal amount.

As a result the sun's rays fall first twenty-three and one-half degrees beyond the point on the planet's surface where they would fall if the orbit were circular, and then twenty-three and one-half degrees short of this position. This gives rise to the two zones forty-seven degrees wide and diametric-

ally opposite each other that have an alternate day and night, each equal in length to forty-four terrestrial days. Between these two lie the two zones, each one hundred and thirty-three degrees wide, one of perpetual day and the other of perpetual night.

On the daylight side of the planet the sun appears to oscillate backward and forward through an angle of forty-seven degrees, and the lowest temperature is higher than that of the boiling point of water upon the earth. Upon the night side the only light is that furnished by the stars that shine with a radiance and glory unknown to us who dwell in a world that is always surrounded by a dense, obscuring atmosphere. Mercury has no appreciable atmosphere and the terrible cold of space prevailing upon the night side of the planet is untempered by warm air currents, such as would flow from the hot to the cold side if the planet possessed an atmosphere.

Here exists a world of extremes, scorched on one side, frozen on the other, while in the zones of alternate day and night that lie between is to be found all the range of temperature that lies between the two extremes. Lack of

atmosphere on Mercury prohibits the existence of life.

The planet reflects about fourteen per cent. of the sunlight it receives, which is slightly less than the amount reflected by the moon's surface and it is believed that its surface resembles that of our satellite in being barren and mountainous.

The axis of the planet is probably perpendicular to its orbit, and it has, for this reason, no seasons, though its greatly varying distance from the sun produces the same effect. The average distance of the planet from the sun is 36,000,000 miles. At perihelion its distance is 7,500,000 miles less than this amount and at aphelion 7,500,000 miles greater. The heat and light received from the sun while in these two positions vary in the ratio of nine to four. A marked increase in the apparent size of the sun would be noticed in passing from aphelion to perihelion and a corresponding decrease in passing from perihelion back to aphelion.

Mercury is not only the smallest of all the planets, but it is even surpassed in size by Titan, one of the satellites of Saturn and Ganymede, the third satellite of Jupiter.

The fact that the perihelion of Mercury moves

faster than it would move if acted upon only by known laws has long been a subject for astronomical investigation, and many theories have been advanced in explanation, among them the theory of the existence of an intra-mercurial planet. According to Leverrier, the noted French mathematician, the mass of such a planet would need to be one-half the mass of Mercury itself in order to account for the actual discrepancy existing between the observed and computed values.

It is virtually certain as a result of careful examination of many photographs taken at the time of total eclipses of the sun that no object exists within the orbit of Mercury with a diameter exceeding thirty or forty miles. There is the possibility that a number of minute bodies of asteroidal size may revolve around the sun within the orbit of Mercury, but it is very improbable that their combined mass would total half the mass of Mercury.

So we may assume that Mercury enjoys the distinction of being the smallest of all the planets, and also the nearest to the sun. It is, in fact, distinctive in many ways. Its orbit is the most elliptical and the most highly inclined to the eclip-

tic of all the planetary orbits. The planet itself is the most rarely seen of all planets visible to the naked eye, and the only one that does not possess an atmosphere.

CHAPTER IV

VENUS, EARTH'S SISTER PLANET

THE silvery radiance of Earth's sister planet, Venus, attracts the attention of all whenever she appears in the western sky, since she is then the most beautiful and conspicuous stellar object in the heavens. Though fully as beautiful when she is visible as "morning star" before sunrise, few of us are up at that time to admire her.

Half way between the horizon and the zenith marks the limit of her departure from the sun. Since the orbit of Venus lies between us and the sun we may never see her in opposition to the sun or upon the meridian at midnight, as we do the outer planets, Mars, Jupiter and Saturn, and, unlike these planets, Venus does not show a circular disk in the telescope, but exhibits all the phases of the moon and when at her greatest brilliancy

appears like a crescent moon in the telescope.

Although Venus approaches nearer the earth than any other celestial body except the moon, the asteroid Eros, and a chance comet, she is, unfortunately, entirely invisible at the time of closest approach. The phase she then exhibits corresponds to that of new moon. Her illuminated face is turned toward the sun, her night side toward the earth. She is then but 26,000,000 miles away and between the earth and sun. Just before and after this time, which is spoken of as the time of inferior conjunction, she appears as a very thin crescent in the telescope, resembling the moon a day or two before and after new moon. Near the time of nearest approach of the two planets some astronomers have observed a faint, ashy light upon the darkened disk of the planet. As Venus has no satellite, this cannot be attributed to reflected moonlight, though some have believed it to be due to earth shine or the light from our own planet reflected from the surface of Venus. It is extremely doubtful that earth shine could be appreciable when a distance of fully 26,000,000 miles separates the two bodies, though our planet presents to Venus at this time the phase of the full moon and

appears much larger and more brilliant to Venus than Venus ever does to us. That it may be due to some electrical manifestation in the planet's atmosphere similar to auroral displays in our own seems more reasonable. It is also near the time of closest approach that a very faint ring of light may be observed outlining the disk of the planet. This is caused by the reflected sunlight from the dense atmosphere that surrounds the planet and furnishes one of many proofs of the existence of such an atmosphere.

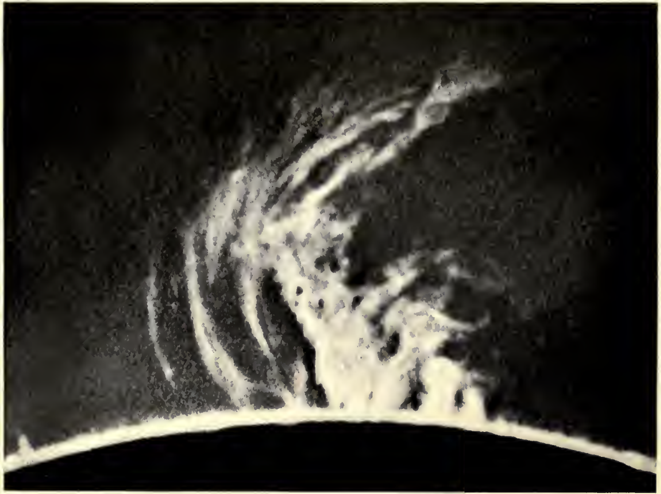
If higher forms of life exist upon our sister planet and dense clouds do not always completely hide the heavens, we may imagine with what interest our own little earth-moon system would be observed at this time of closest approach of the two bodies. A most beautiful and interesting double star our earth-moon system must appear from Venus. Our satellite, of course, would be plainly visible to the naked eye from Venus and its constantly varying positions with reference to our planet would soon reveal the fact that it is in revolution around the earth. How intelligent beings there might puzzle over the earth's continents and seas, changing vegetation, polar snow caps, clouds,

daily rotation and sensational changes! Just as we puzzle over Mars and its baffling surface markings may not another world be puzzling over our peculiarities? This may be most unlikely, but it is a possibility. About the planet Venus we know very little except that its age may be very nearly that of our own planet and that it is more suited to the development of forms of life such as we have upon the earth than any other planet in the sun's family, provided it rotates upon its axis once in about twenty-four hours. Upon this point we are still in doubt, for observations of Venus are always made at a disadvantage, owing to the density of its atmosphere and the fact that it is always more or less unfavorably situated for observation.

Many markings have been observed upon Venus, but, unfortunately, they do not appear the same to all observers, and it is still impossible to say with certainty whether the actual surface of the planet or cloud formations are seen. Even determinations of the planet's period of rotation by means of the spectroscope contradict each other flatly. After years of observations we do not yet know whether Venus rotates on its axis in twenty-four hours or in two hundred and twenty-five days,

the period of its revolution around the sun. In the latter case it would always turn the same face toward the sun just as our satellite always turns the same face toward the earth. If this state of affairs exists on Venus one side never sees the sun, the other side never sees the heavens studded with myriads of stars, but feels the torrid heat of a sun immovable in the sky, possibly screened from view by friendly clouds. The planet's dense atmosphere would tend to mitigate the two extremes of temperature found on opposite sides of the planet by a constant flow of air currents between the two sides. In fact, there would be, under such circumstances, storms of frightful intensity continually raging over the planet's surface. If, on the other hand, Venus turns on its axis in approximately twenty-four hours no other planet in the solar system so closely resembles the earth.

The diameters of the two planets differ by about 200 miles, and in mass, density and surface gravity they are nearly the same. A man weighing 170 pounds upon the earth would weigh 145 pounds upon Venus. We could move about a little more easily upon Venus than we do upon our own planet. We would probably find the atmosphere very much



SOLAR PROMINENCE 140,000 MILES HIGH

(Photographed July 9, 1917, with the 60-ft. tower telescope of the Mt. Wilson Observatory)

the same. The reflecting power of the atmosphere of Venus is very nearly the same as that of the thunder heads we often observe in our summer skies, which seems to indicate a cloud laden atmosphere for our sister planet. Though some observers have placed the density of the atmosphere of Venus at twice the density of the earth's atmosphere, others believe they are virtually the same. It is in the amount of light and heat received from the sun that we note the greatest difference between the two planets. Venus receives nearly twice as much light and heat from the sun as we do. This may seem to us a rather uncomfortable amount, and we wonder how the inhabitants stand it, but possibly they may wonder how we exist upon a planet that is so poorly lighted and so cold. Upon our own planet we find life flourishing under conditions of great diversity. Countless forms of life exist under the sea and upon the surface of our planet, in the torrid heat of the tropics and the frigid cold of the polar regions. So life upon Venus does not seem so improbable unless it shall be determined eventually that the planet always keeps the same face turned toward the sun. In case it shall be found that Venus

rotates on its axis once in about twenty-four hours we can hardly escape the conclusion that the life process must be running its course there as well as here. Given all the essentials for the development of life,—air and water, heat and light in abundance,—it seems almost too much to assume that such a world is devoid of life.

CHAPTER V

HOW OLD IS MOTHER EARTH?

THE age of Mother Earth is a perplexing question, not only for astronomers but for geologists and biologists as well.

There are many different methods of attacking the problem, but all agree that the long series of evolutionary changes that have taken place upon our planet could not have been brought about in any period of time less than tens of millions of years. This applies, moreover, simply to the duration of the life process upon the earth and does not include the ages that must have elapsed from the earth's beginning to the time when it was in a condition suitable for the production of life.

Geologists and biologists find their evidence of the earth's age in the condition of its crust, in the stratification of its rocks and the fossil remains of

various forms of life formerly existing upon it, while for the astronomer the solution of the problem is dependent upon how long the sun's light and heat have been supplied at the present rate. Barring outside interference, such as the close approach of a passing sun, the duration of life within the solar system depends entirely upon how long the sun's supply of radiant energy can be maintained.

Considering, first, the evidence furnished by the biologist for the duration of life upon our planet, through examination of fossil remains in rocks of different geological formations, it has been found that the earliest and most primitive forms of life appeared in rocks of earliest formation and a chain of increasingly higher and higher forms of life appeared as the age of the geological formations decreased. In rocks of the latest formation the fossil remains of the highest forms of life appeared. Noted biologists have placed the period necessary for this excessively slow process of evolution as high as two billions of years, and though some feel this is too high, none can see how such a long chain of evolution could have been completed in less than some hundreds of millions of years.

The time required for the disintegration of the

original earth material, its deposition on the bottom of lakes and oceans, stratification and the numberless repetitions of the process that are known to have taken place could not be less than one hundred millions of years, according to the most conservative estimates of geologists.

Another geological method of determining the age of the arth is to compute the time required for the oceans to acquire their present salinity. Since the rivers carry to the oceans various salts in solution and the water evaporated from the oceans leaves the minerals behind the salinity of the oceans is continually increasing. There is of course some divergence of opinions as to how rapidly the salts were carried down to the oceans in the earliest ages, but no computation makes the time since the oceans first started to form less than sixty millions of years and some estimates run as high as one hundred and forty millions of years.

The most recent geological method of determining the earth's age followed upon the discovery of radio-active substances. Uranium degenerates by the gradual breaking up of its atoms and radium, lead and helium are evolved.

The relative amounts of these elements in some

rocks show how long the process has been going on in them. This method appears to give a greater age for the earth than that obtained by any other method. Those who have made a special study of this method have arrived at the conclusion that some of these rocks may be two billion years old, and that their age at least must be measured by hundreds of millions of years.

For the astronomer the vital question is, How long has the sun kept up its present rate of radiation? Manifestly all life processes upon our earth are dependent upon the light and heat furnished by our sun. As soon as the supply begins to appreciably and continually diminish life will begin a rapid decline. The ruler of our solar system is radiating heat and light into space at an extravagant rate. The apparent area of the earth as seen from the sun is about one-fifteenth the greatest apparent area of Venus as seen from the earth. From the sun the earth would appear as a small point upon the celestial sphere. And yet how much heat does our small planet intercept at a distance of ninety-three million miles from the sun? It has been estimated that the rate at which solar energy is intercepted by the whole earth

is 230,000,000,000,000 horse-power. The total amount of the sun's radiant energy must therefore be inconceivably great, for less than one two-billionth of the total amount given forth is intercepted by the earth. Except for the amount intercepted by the other planets, placed at ten times the amount the earth receives, the boundless supply of radiant energy given forth by our sun is wasted, according to the ideas of man. It travels onward through interstellar space at the rate of 186,000 miles per second to the stars beyond.

The theories that the sun's heat is kept up by the combustion of the materials of which it is composed, or that it is simply cooling off without any replenishment of its loss of heat, lead to absurd results and receive no consideration from astronomers. In neither case, under the most favorable suppositions, could its present rate of radiation be kept up for more than two or three thousand years.

A theory that is more plausible than either of the preceding considers that the sun's heat is maintained by the impact of meteoric matter. Astronomers have estimated that if a meteor should fall into the sun from the distance of the earth its velocity would be about 380 miles a second and the

heat produced by the impact would be about 23,000 times the amount produced by the combustion of an equal amount of carbon and oxygen. The strongest objection to this theory is that it would require a much larger total mass of meteors than actually exists. Not a sufficient amount of meteoric matter could possibly exist within the earth's orbit for this purpose, and if it came from beyond the earth's orbit the earth would also receive sufficient amounts to materially affect its temperature. As a matter of fact the amount of heat that the earth actually does receive from meteoric matter is negligible.

The theory that the sun's heat is kept up by its own contraction is the only one that at all fits in with the requirements, and there are serious objections to regarding contraction as the only source of supply of the sun's heat. Nevertheless, it can be shown, following the methods of Helmholtz and using the most recent data for the sun's rate of radiation, volume and mass that a contraction of 120 feet a year in the sun's radius would produce as much heat as the sun now radiates annually. This amount of contraction is so small that ten thousand years would elapse before the resulting

change in the apparent diameter of the sun could be detected from the distance of the earth with the assistance of our most powerful telescopes. So whether the sun actually is contracting cannot be determined observationally. A weak point of the contraction theory is that the present rate of radiation of the sun could not have been maintained by contraction alone for more than twenty-five million years at the most. This would imply that all the great series of changes that geologists and biologists have every reason to believe extended over tens if not hundreds of millions of years were crowded into a period of approximately twenty-five million years. Most astronomers consider it more reasonable to assume that the contraction of the sun does not supply all of its heat than to assume that all the evidence of other scientists collected from a variety of independent sources is wrong.

With the discovery of radioactivity it was believed that the sun's supply of heat might be sustained partly by disintegration of uranium and radium, inasmuch as such disintegration is accompanied by the evolution of an enormous amount of heat. Although it is not known definitely that

these substances are found in the sun, helium, one of the products of the disintegration of uranium and radium, occurs in great abundance in the sun, and, in fact, was first discovered there. Investigations showed that if one part in eight hundred thousand of the sun were radium, heat would be produced from this source alone as fast as the sun is radiating it at present but that in two thousand years hence half the radium would be gone and the production of heat would be diminished one-half, or that two thousand years ago the amount was twice the present amount and the production of heat was twice as fast. Since this is not in accord with the facts we can conclude that the sun's heat is not due to the disintegration of radium to any great extent. Uranium yields results just as unsatisfactory.

Of one fact we are certain, that an unbroken chain of life has existed upon our planet for tens of millions of years at least and in this period there has been no great temperature change and no signs of a steady progressive cooling of the sun. Glacial epochs and warmer eras have alternated with each other, but no sudden or gradual change great enough to destroy the chain of life has ever arisen.

CHAPTER VI

MYSTERIES OF MARS

THE ruddy planet Mars, always an object of special interest to the inhabitants of our planet, Earth, because of its nearness and the still unexplained mystery of its surface markings, is best studied when it is in opposition to the sun.

It is then on the meridian at midnight and visible throughout the entire night, rising in the east at sunset and setting in the west at sunrise.

At a near opposition, which occurs once in fifteen or seventeen years, Mars is a most striking object because of its fiery red color. These near oppositions always occur in August, and the next one will take place in 1924, when Mars will be only 34,000,000 miles from the earth. Mars will also be in opposition to the sun in April, 1920, and in June, 1922, since oppositions of Mars are separated

by intervals of two years and two months. The next three oppositions will be particularly favorable for observations of the surface markings of this planet.

Owing to the rarity of the atmosphere of Mars it is possible to observe actual surface markings on this planet. Mars has no vast oceans such as exist upon our own planet. Extensive desert tracts predominate and give the planet its characteristic reddish color. The comparatively few dark spots that are visible lie in the Southern Hemisphere and are generally believed to be due to vegetation. The atmosphere of the planet is so rare that the climate is one of extremes, with a great daily range of temperature. The seasons resemble those found upon the earth, for the two planets have nearly the same inclination to the ecliptic, but the Martian year is nearly two of our years in length and the Martian seasons last twice as long as our own. The planet turns on its axis in a little more than twenty-four hours, so the Martian day and night nearly equal the terrestrial day and night in length.

In addition to the extensive, reddish, desert patches and the dark patches due to vegetation the north and south polar snow caps are distinctive

features of the Martian surface, and their appearance and disappearance with the seasons is well known. It is only when we come to a consideration of the Martian "canals" that we meet with a divergence of opinions among astronomers. Though there are still astronomers who have never seen the canals and astronomers who deny their existence, there seems to be fully as many who have observed them and are firmly convinced of their actuality.

The theory of the late Prof. Lowell concerning the much disputed canals was that they were channels of water bordered by strips of vegetation and were built by intelligent beings for the purpose of directing the water from the melting polar caps through the desert tracts to the opposite hemisphere. According to this theory we see not the water channels but the strips of vegetation growing upon the banks. More recently Prof. W. H. Pickering has advanced a theory concerning the nature of the larger and more important canals which he speaks of as the "The Theory of Aerial Deposition."

According to this theory the major canals are marshes or natural reservoirs fed by storm ladened air currents that are constantly passing from re-

gions of high pressure surrounding the melting polar cap to the equatorial regions of low pressure. The rotation of the planet upon its axis from west to east and the resistance of the atmosphere encountered by these air currents in their passage toward the equator would give them a curving tendency. Therefore the marshes or canals fed by these air currents through precipitation of their moisture during the chill Martian nights would also show the same curvature. By measuring the radius of curvature for the more important north polar canals Prof. Pickering arrived at a determination of the velocity with which the moisture ladened air currents blow and he found that the highest velocity of the wind over any of the southward leading canals was about 230 miles per hour. This was the velocity found for the northern portions of one of the longest canals shortly after the storm had started from the polar regions.

At the southern end of its course the velocity was reduced to about nineteen miles per hour.

Prof. Pickering concluded from an extensive study of the curvatures of various canals that it is reasonable to assume that the wind in the northern hemisphere of Mars does at time reach a velocity of

230 miles per hour and that the maximum theoretical velocity cannot be much less than 324 miles per hour nor the corresponding pressure of the atmosphere less than one-quarter of the pressure of the terrestrial atmosphere. This conclusion is borne out, he believes, by other considerations such as the small force of gravity on Mars, the transparency of its atmosphere and the lack of permanent oceans. Upon this assumption the boiling point of water upon Mars comes out as 150 degrees F. approximately.

As the north polar cap melts and diminishes in size, the amount of moisture carried southward by the air currents should also diminish, and therefore the atmospheric pressure and consequently the velocity of the wind. As a result the curvature of the canals should change slightly and they should shift with the season. The greater the velocity of the wind the less it will be deflected in its southward journey. A slight shifting of the polar canals has been noted at previous opposition of Mars, and it is particularly desired to investigate this question of the shifting of the canals at favorable oppositions.

According to the theory of Prof. Pickering the

major Martian canals, those leading from the north polar cap southward to the torrid zone, are not necessarily the work of intelligent beings, but they do serve the purpose of furnishing the northern hemisphere with a supply of water in the form of natural marshes or reservoirs during the long northern summer until the south polar cap starts to melt at the coming of the autumnal equinox. Since Mars has no great oceans these marshy tracts are most essential for the maintenance of vegetable and possibly animal life upon the planet.

In addition to these larger and more important canals there are many faint, narrow canals of a secondary type. About 500 canals of the faint type have been located and named at the Lowell Observatory. They are characterized by great uniformity and straightness and by the fact that they appear late in the season and in great numbers.

Prof. Pickering, who is one of the leading observers of Mars, considers that the question of their origin is still unsettled. It is unknown whether they are artificial or an illusion, or mark the path of occasional local storms. As to the visibility of the canals of Mars, this depends, according to Prof.

Pickering, largely upon the conditions of our own atmosphere. Under excellent "seeing" conditions, it is possible, he believes, to see all of the more prominent canals with a four-inch telescope.

CHAPTER VII

THE ASTEROIDS

IN the vast expanse of space that separates the orbit of the outermost member of the terrestrial group of planets, Mars, from the nearest and largest of the major planets, Jupiter, is found that numerous host of tiny bodies known as the planetoids or asteroids.

Lawful members of the solar system they must be considered, although they are distinguished from the eight large planets not only by their extreme minuteness, which renders the largest of them invisible without telescopic aid, but also by a greater range in the shape of their orbits and in the inclination of these orbits to the earth's path around the sun. The paths of the eight principal planets can hardly be distinguished from perfect circles and they lie very nearly in the same plane. The

asteroids move in paths that vary from almost perfect circles to highly elongated ellipses and these paths are sometimes inclined at an angle of nearly 35 degrees to the planetary orbits, though the average is much less. It is truly remarkable, however, that all of the asteroids so far discovered, more than eight hundred in number, move in the same direction around the sun as do the eight chief members of the solar system, from west to east. This cannot be the result of chance but points to a common origin with the other members of the system. According to the planetesimal theory of the origin of our solar system the asteroids may be regarded as particles of the original nebula that escaped fusion into one greater planetary mass, due either to an absence of a planetary nucleus in their immediate neighborhood or to the nearness of the huge Jovian mass under whose disruptive influences they have been kept apart. So interwoven are the paths of the planetoids that if they were made of wire not one could be lifted without drawing the others with it. That they have so far escaped collisions is due to the fact that their paths lie in planes inclined at different angles. The noted little asteroid Eros has escaped collision with the planet

Mars only because of the inclination of its orbit.

At the time of the discovery of the first asteroid, January 1, 1801, the first day of the nineteenth century, astronomers were making preparations to search for a planet in the enormous gap existing between the orbits of Mars and Jupiter. According to Bode's law, to which is also due, indirectly, the discovery of the planet Neptune, a planet was to be looked for at about 2.8 times the earth's distance from the sun. This peculiar law, which has no scientific foundation, gives a rough approximation to the relative distances of the first seven planets from the sun, as well as the average position of the asteroids. According to this relationship noted by Bode, if the number 4 is added to each number in the series 0, 3, 6, 12, 24, 48, 96, the resulting series, 4, 7, 10, 16, 28, 52, 100, represents roughly the relative distances of the planets Mercury, Venus, Earth, Mars, Jupiter and Saturn from the sun, with no planet to correspond to the number 28. It was this gap in the distances that led the astronomers of that day to suspect the existence of another planet at 2.8 times the earth's distance from the sun. The first asteroid discovered was at approximately 2.8 times the earth's

distance from the sun. It was found later that the planet Uranus, undiscovered at the time Bode's law was first advanced, continued the series, since its distance from the sun corresponds to the number 196. The law fails, however, for Neptune. The planetoids are scattered throughout the entire space between the orbits of Mars and Jupiter. A few of them even come within the orbit of Mars and a few others are found beyond the orbit of Jupiter, but they occur in greatest numbers at the distance corresponding to the number 28 in Bode's series, or 2.8 times the distance from the earth to the sun.

The first asteroid was discovered by Piazzi at Palermo and was, by his wish, named Ceres, for the tutelary goddess of Sicily. A year later the astronomical world was surprised by the discovery of a second small planet at almost the same distance as the first. This was named Pallas. In 1804 a third, Juno, was discovered; in 1807 a fourth, Vesta. These four are the largest of the asteroids and their diameters are respectively 485, 304, 118 and 243 miles, as determined by Barnard with the 36-inch telescope of the Lick Observatory. Most of the asteroids are much smaller. Many do not exceed

five or ten miles in diameter. After the discovery of Vesta in 1807 no other asteroid was discovered until 1845, when Hencke's long search of fifteen years was rewarded by the discovery of Astræa. In 1847 three more were discovered and from that time to the present, no year has passed without the discovery of at least one asteroid. Since 1891, when photography was first used for the purpose, planetoids have been discovered in great numbers. The telescope with photographic plate exposed in place of an observer is made to follow the stars for several hours. In this time the planetoid will move an appreciable distance. When the plate is developed the star images appear as clearly defined dots, but the asteroid has left a telltale trail upon the plate about a twentieth of an inch in length. Following the discovery a provisional designation is given to the object until it can be determined definitely whether it is a new asteroid or simply one rediscovered, or possibly a new comet. Wolf's comet, discovered photographically in this way, was at first mistaken for an asteroid. New plates must be exposed or old plates reëxamined to get additional positions of the object from which its orbit is computed. Peculiarities of motion soon show

whether it is asteroid or comet or possibly a faint satellite of Jupiter or Saturn.

In 1898, when astronomers were growing weary of their large and ever increasing family of asteroids, already numbered by hundreds, and when it was becoming a perplexing question as to how they were to be named and how time could be spared from more urgent work to compute their troublesome orbits, asteroid No. 433, known as Eros, was discovered. This tiny asteroid, less than twenty miles in diameter, has more than repaid all the work and trouble occasioned by the other members of the family and has furnished astronomers with probably the best method they possess for determining the solar parallax and the dimensions of the solar system in miles and the distances of the stars and the dimensions of our whole stellar system as well. It is possible to determine the relative distances of the members of the solar system without knowing the actual distance between any two of them, but we can form no idea of the extent of the solar system in miles and of the universe in light years until we actually measure the distance between two of the bodies. Eros comes nearer to the earth than any other known celestial body with

the exception of the moon. At nearest approach it is only 13,500,000 miles away, and its nearness and clear, starlike image make it an ideal object for the determination of the important constant of the solar parallax and the distance from the earth to the sun, the astronomical unit of distance. Eros was in a particularly favorable position for observation in the winter of 1900-1901, and a series of valuable observations were obtained. Thirty years must pass before it will be as favorably located.

Eros aroused still further interest in 1901 when it was observed to vary rapidly in light. During February and March of that year its period of light variations was 2 hours 38 minutes. Its light at minimum was less than one-third that of maximum. By May of the same year this peculiar variability had ceased. It was suggested that it might be explained by assuming that the planetoid consisted of two bodies revolving close together so that one body would appear to eclipse the other in certain positions of the orbit. According to another view the asteroid has a surface that is very rugged and uneven and reflects light unequally. In other words, like most of the asteroids, it may be considered to be simply a huge rock.

CHAPTER VIII

THE PLANETS JUPITER AND SATURN COMPARED

WHEN the two largest planets in the sun's family, Jupiter and Saturn, appear in the heavens at the same time, as frequently happens, they can be readily distinguished from each other since Jupiter far surpasses Saturn in brightness, not only because it is much larger, but also because it is much nearer to the earth. On the date of its opposition to the sun, the giant planet Jupiter is approximately 400,000,000 miles away, while Saturn is nearly twice as far from the earth.

The two planets closely rival each other in popular interest. Saturn's vast system of three concentric rings, more than 170,000 miles in outer diameter, composed of swarms of minute moonlets of meteoric dimensions revolving each independently around the planet, makes it absolutely unique

in the solar system. Jupiter, on the other hand, on account of his satellites and belts, is by far the most interesting to observe of all the planets, as well as the largest and most imposing, and the one most subject to constant change and variety of color and markings. Though Saturn is also, beyond doubt, the scene of wildest tumult, its surface changes are rendered more blurred and indistinct by an additional 400,000,000 miles of intervening space.

There is much similarity in the surface markings of the two planets, which are, in reality, phenomena of the dense enveloping gaseous strata of their atmospheres. Belts or bands of gaseous vapors are always to be seen in the atmospheres of both planets, though the belts of Saturn are far more indistinct than those of Jupiter. They vary continually in shade, numbers and position, but always lie in a direction parallel to the planet's Equator, being drawn into this position by the extremely rapid peripheral motion of the outer gaseous envelopes of these planets.

Both Jupiter and Saturn rotate on their axes in approximately ten hours, less than half the period that the earth requires to turn on its axis, though

its diameter is only about one-tenth that of the outer planets.

It is an interesting and significant fact that the general color of the planet Jupiter fluctuates with the sun spot period, appearing palest when spots are most plentiful on the sun and more reddish as the frequency of sun spots decreases. This is due to the fact that the solar activity that produces sun spots also produces certain atmospheric effects upon the planets. It is known that high clouds, such as the cirrus clouds in the earth's atmosphere, form more readily under the solar influences that produce sun spots and similarly it is believed atmospheric changes are produced in the dense gaseous envelope of the giant planet.

Marked changes are also noted at times in the color of the ringed planet. According to observations made at the Lowell Observatory at the opposition of 1916 the planet was at that time of a pinkish brown color and conspicuously darker than its rings.

The great distance of Saturn makes it very difficult to observe the finer details of its surface changes. It is for the same reason that Saturn's interesting satellite family of nine members,

exactly equal in number to that of Jupiter and fully as impressive in the actual size of its various members, arouses less interest than the family of the giant planet.

Titan, the largest of Saturn's satellites, a world in itself, fully three thousand miles in diameter, can be seen readily enough with the smallest telescopes as an eighth magnitude star. Rhea, Dione and Tethys, whose diameters are between twelve hundred and fifteen hundrd miles, may also be seen fairly well with a four-inch telescope, which will also show the rings beautifully.

Japetus, the most distant of the satellites of Saturn, with the exception of tiny Phoebe retrograding at a distance of eight million miles, is almost the twin of our own moon in size. It lies at a distance of two and a quarter million miles from Saturn and requires seventy-nine days to make one revolution around the planet. It is of special interest to astronomers, owing to the fact that its light is conspicuously variable. When on the western side of Saturn it is always brighter than when it is on the eastern side, and this is believed to be due to the fact that it always keeps the same face turned toward Saturn just as our

own moon always keeps the same face turned toward the earth. The variability of light probably arises from a difference in the reflecting power of the two sides, different sides of the satellite's surface being turned toward the earth in the two positions.

Observations made of the first two satellites, Mimas and Enceladus, by E. C. Slipher of the Lowell Observatory seem to show that these satellites also keep the same side turned toward the planet. They are both small bodies between 500 and 1,000 miles in diameter that skirt rapidly around the outer edge of the ring system distant from its outer edge 30,000 and 70,000 miles respectively.

The possessor of a small telescope will find the four largest satellites of Jupiter easier and more interesting objects to observe than Saturn's satellites. A few extremely sharp-eyed persons have glimpsed these four satellites with the naked eye, and the least optical aid will reveal them. Their journeyings around the giant planet and all the varied phenomena of the eclipses, occultations, shadows and transits can be observed with interest and profit by means of a three-inch tele-

scope. The five fainter satellites are beyond the reach of all but the most powerful telescopes, as are also the four smallest satellites of Saturn.

Jupiter and Saturn resemble each other not only in the size of their satellite families and the nature of their surface markings but also in the fact that they are both composed almost, if not entirely, of matter in a gaseous state. The extremely low density of the two planets, less than that of the sun in both cases, and in the case of Saturn only sixty-three-hundredths that of water, the lowest for any planet in the solar system, contrasts sharply with the great density of the terrestrial planets. Our own planet Earth, with its surface crust and rigid interior, possesses a density five and one-half times that of water.

The two planets, Jupiter and Saturn, are therefore as different in physical constitution from our own world as it is possible for one to imagine. They possess no stable surface crust, though liquid and solid particles of matter may occur locally or be suspended in dense gaseous vapors. All is a whirling, seething, tumultuous mass, characterized no doubt by great heat, in the deeper strata at least, where the pressure of overlying gases must

be tremendous. A small solid or liquid core may exist in each planet, but the general belief is that both planets are almost entirely gaseous. Though the two planets may emit a certain amount of heat to their satellites, the complete disappearance of the satellites of Jupiter when they pass into his shadow shows that they receive no appreciable light from the huge planet other than reflected sunlight.

A marked difference between these two planets that have so many characteristics in common is found in the positions of their axes of rotation with respect to their paths around the sun. The equator of Jupiter is inclined only three degrees to its orbit. As a result it has no change of seasons. Saturn's equator, on the other hand, as well as its ring system, which lies nearly in the same plane, is tipped twenty-seven degres to the plane of its orbit. This inclination of equator to orbit is the greatest for any planet in the solar system, exceeding that of the Earth by several degrees. As a result seasonal changes on Saturn would be more pronounced than they are on the Earth were the effect not modified to a great extent by the very great distance of Saturn from the sun.

In these two largest members of the sun's family we see much that is similar and much that is distinctive. No two planets of the solar system are modeled exactly along the same lines. This individuality among the various members of the same planet family is but a reflection of the infinite variety that characterizes all the wonderful formations far beyond that form a part of the same universe to which our sun and his family belongs.

CHAPTER IX

SATURN THE RINGED PLANET

OF all the brighter planets Saturn is the least interesting to observe with the naked eye and one of the most interesting viewed through the telescope.

It shines with a dull leaden light, very different from the fiery red of Mars, the sparkling beauty of Venus, or the splendor of Jupiter.

Saturn is usually spoken of as the ringed planet and is unique in the solar system for several reasons. It is the only planet that is lighter than water, the only one that would float if thrown into a body of water large enough to contain it, and it is surrounded by a system of rings of marvelous appearance.

There are three of these thin, flat, concentric rings, two bright ones and a third called the dusky

or crepe ring. The outer ring, which is called "A," has an exterior diameter of 173,000 miles and a width of 11,000 miles. It is separated from "B," which is much brighter, by a division of 2,200 miles of uniform width all around known as Cassini's Division. The third or dusky ring, "C," was discovered in this country in 1850 and is comparatively hard to see. Its width is equal to that of the outer ring and its inner edge is only 6,000 miles from the surface of the planet. The ring "B" is about 18,000 miles wide. The thickness of the ring system is less than 100 miles and its weight is next to nothing. "Immaterial light" the rings have been called by the astronomer Struve. They are of perfect symmetry and when seen in a telescope fill the observer with admiration and awe.

As to composition, they are now known to be swarms of tiny satellites or moons, nothing more than meteors in size, and they are in constant revolution around Saturn. Every 15 or 17 years the rings entirely disappear from view for a short time even in the most powerful telescopes. This is due to the fact that once every 15 or 17 years the earth is exactly in the plane of the rings

and the edge of the rings is directly in the line of sight. This causes the entire disappearance of the rings from our point of view. The next disappearance wiil occur in 1922.

For the remaining time the earth is either above or below the plane of the rings and we either look down upon them from above or up from beneath, as the case may be, and so see them at varying widths.

In addition to the rings Saturn has nine satellites, and the outermost is at a distance of about 8,000,000 miles from Saturn. So extensive is this vast system, truly a solar system in miniature! The names of the satellites in order of distance outward from Saturn are Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Japetus and Phoebe. By far the largest of these is Titan, which is of the same size as the planet Mercury.

The most remarkable of the satellites is Phoebe, because, while all the other satellites of Saturn follow the usual direction of revolution in the solar system and revolve from west to east around their primary, Phoebe revolves from east to west or retrogrades, as it is called.

The periods of revolution of the satellites around

their primary show great diversity, ranging from $22\frac{1}{2}$ hours for Mimas, which skirts along the outer ring, to 16 months for Phoebe, the most distant of all. In shape Saturn is the most flattened at the poles of any of the planets. It is decidedly oval in appearance. This is very noticeable at the time of disappearance of the rings, when we get an unobstructed view of Saturn's globe. Saturn also has belts, similar to those of Jupiter, but fainter in color and more indistinct.

Both of these planets are apparently in a much earlier stage of development than the earth. Saturn is a world in a state of chaos, and the dense canopy of clouds, with which it is surrounded, points to a surface of intense heat, for Saturn is too far from the sun to have its clouds raised by solar heat. They must be the product of its own seething heat. This is a world in the making and the dense clouds with which it is surrounded will probably settle down upon its surface as oceans in ages to come.

It is hard for us to realize as we look upon this planet of leaden hue, not so much brighter than a first magnitude star, so great is its distance from us, that in size our earth compares with it as a

pea with an orange, and that, as the celebrated French astronomer Flammarion has said, the earth might roll upon the ring system like a ball upon a road.

CHAPTER X

PLAIN FACTS ABOUT THE MOON

ALL the planets in the solar system, with the exception of Mercury and Venus, are attended by satellites. Saturn has nine, in addition to his ring system. composed of numberless tiny moonlets.

Jupiter also has nine moons, Uranus four, Mars two and Neptune one, while our own planet, Earth, has a satellite which is in one respect unique in the solar system. The ratio of its size to that of its primary far exceeds that of any other satellite. Its dimensions are quite comparable with those of the earth. Its diameter is about 2,160 miles. The earth's diameter is about 7,900 miles.

Fifty moons would equal the earth in volume, although it would take eighty-one times the mass of the moon to equal the mass of our planet, as

the lunar density is only six-tenths that of the earth. The entire surface of the moon about equals North and South America in area, though about forty per cent. of its surface we can never see, since our satellite always turns the same face toward us.

Titan, the largest satellite of Saturn, has a diameter of 3,500 miles, and is larger than the planet Mercury, but it would take 4,600 Titans to equal Saturn in mass. Ganymede, the largest satellite of Jupiter, is almost exactly of the same size as Titan, but its mass must be increased 11,000 times to equal that of Jupiter.

Neptune's moon about equals our own in size, but is a very tiny object compared with its primary, which has a diameter of 35,000 miles. The largest of the satellites of Uranus is only 1,000 miles in diameter and the two tiny moons of Mars average about ten miles in diameter.

Our own satellite is a most beautiful and interesting telescopic object and even when viewed with an opera glass, its apparent distance is reduced one-half. With moderate sized instruments we may view it at an apparent distance of about 1,000 miles. The greatest telescopes make it appear only sixty miles away, but we must remember such a

view is by no means clear and distinct, for atmospheric imperfections are magnified as well.

Even with moderate sized instruments, however, any lunar object a mile or so in diameter is readily discernible, and with large instruments and a trained eye and good atmospheric conditions, any object a quarter of a mile in diameter could be detected. If large cities existed upon the moon very moderate instruments would show them.

The question of life upon the moon is readily disposed of, for we know that there is neither air nor water there. The moon's period of rotation upon its axis is equal to its period of revolution around the earth. In other words, it always turns the same face toward the earth and its day is two weeks long. Fourteen days of light are followed by fourteen days of darkness.

During the lunar day the barren surface of the moon is exposed to the intensity of the solar rays, unmitigated by any protecting atmosphere. The temperature must rise during this scorching period as high as the boiling point, to fall during the long, dark night that follows nearly to the absolute zero of interplanetary space.

Because of the absence of an atmosphere upon

the moon there is no diffusion of light. Shadows are inky black and the stars above shine by day and by night, in an inky sky. Stars that we need a field glass to see upon the earth would be readily seen with the naked eye upon the moon. The Milky Way, so dimly seen by us, is a gorgeous spectacle in the lunar heavens. The solar corona and prominences are always visible, as is also the zodiacal light. The planet Mercury, so elusive to our eyes, is easily observed from the moon. Both stars and planets shine far more brilliantly there against a background that is always black.

As regards the lunar landscape, even the smallest telescope shows us many features not visible to the naked eye. Extensive dark and light regions give our satellite its spotted appearance. The light portions are always rough and the dark ones comparatively smooth. The latter have been incorrectly termed maria or seas ever since the time of Galileo, who believed these grayish patches were really vast expanses of water. They are designated by such fanciful names as Sea of Clouds. Sea of Serenity, Lake of Dreams, etc.

The most distinctive lunar features are the craters, numbered by the thousands, and possibly in-

correctly named, for we naturally think of a crater as formed by volcanic action and it is by no means certain that the craters of the moon are of volcanic origin, though this belief is still held by some astronomers.

The larger craters, which are often from fifty to one hundred miles in diameter, are usually comparatively shallow, about three miles or less in depth. Frequently a single mountain a mile or so in height rises from the centre of the crater, or ringed plain, as it is often called. It has been estimated that there must be fully 100,000 craters, ringed plains and craterlets upon the surface of our satellite. It is these formations that make its face appear so pockmarked and scarred.

A conspicuous crater, visible even to the naked eye, is Tycho, often called "the metropolitan crater of the moon." It lies near the south pole of the moon, has a diameter of over fifty miles and is nearly 17,000 feet deep. It has a central hill 6.000 feet high and is a typical lunar crater.

The moon is also remarkable for its systems of rays or streaks radiating from prominent craters. These extend for vast distances, nearly 2,000 miles in one instance. Those surrounding Tycho emanate

THE MOON—AGE, 8½ DAYS
(Photographed by Ritchey at the Yerkes Observatory)

from it like brilliant lines of longitude. They appear to be neither elevated nor depressed, but run in remarkably straight lines over hill and plain interrupted by no feature of the lunar landscape.

These rays still remain one of the riddles of the moon, though, according to those who believe in the meteoric origin of the moon they were caused by the splashing of some light colored material when an unusually large meteor struck the lunar surface. Supporters of this belief point also to the fact that large deposits of sulphur upon the moon's surface have been photographed in ultra-violet light.

A number of craters are surrounded by these streaks. Copernicus, a crater a little northeast of the centre of the moon's disk, has a remarkable system of feathery streaks.

Clefts, or rills, as they are called, are also seen in large numbers upon the moon. They are often more than 100 miles long, but are usually extremely narrow, often mere cracks in the surface, half a mile or so wide. Mountain chains also exist upon the moon similar to mountain chains upon the earth. There are the lunar Alps and Appenines, with peaks running up to 20,000 feet in height.

On the extreme southern edge of the disk are two mountain chains spoken of by the French astronomer Flammarion as the "mountains of eternal light," for the sun never sets upon these peaks, one of which is 7,000 feet higher than Mount Everest.

From the moon the earth appears about thirteen times as large as the moon does to us. Seen from any point upon the visible lunar disk it would appear practically immovable in the sky, its altitude varying for different positions on the moon's surface. The diurnal rotation of the earth would be clearly seen, as would also its continents and seas, polar caps, mountains and plains, its clouds and storms. It would exhibit all the phases that the moon does to us in reverse order.

Many theories of the origin of the moon have been advanced, but all seem to present some difficulties. Our satellite furnishes us many unsolved problems. A belief in the meteoric origin of the moon is now quite general. According to this belief the earth was surrounded in the early stages of its existence by a ring of meteoric matter. The material forming the ring gradually gathered into one mass, our present moon, whose pitted face gives

evidence of the bombardment it received from meteoric masses within the ring.

According to this theory our satellite has always been a dead world, a cold and lifeless mass of meteoric rock. It has never felt the pulse of life or undergone the mighty changes that have passed over its ruling planet, the Earth. It has remained a cold and silent witness to vast evolutionary processes going on upon a neighboring world such as it could never experience for itself.

CHAPTER XI

SOME UNSOLVED PROBLEMS OF THE MOON

A MOST troublesome little member of the sun's family is our satellite, the moon. The nearest to the earth of all the heavenly bodies and the most easily observed, the moon presents as many unsolved problems as the stars themselves.

There are more theories advanced to explain the origin of the lunar craters than there are to explain the nature of the "canals" of Mars. We hear many conflicting theories. First there is the theory of a terrific explosion from within and the resulting deluge of the lunar surface with an outflow of highly heated material of spongy consistency with its bursting bubbles of gas, to be followed later by secondary explosions and more deluges. Then there is the opposite theory of intense bombardments by meteoric masses from with-

out that have disfigured and pitted the face of our satellite.

There is also the theory that the moon was once a part of the earth and that the two gradually separated and the distance between them increased slowly under the complicated action of tidal forces exerted by the sun as well as by the earth and moon. And there is another theory that the moon never was a part of the earth but has been captured by our planet.

There is one problem presented by irregularities in the motion of the moon that transcends all other lunar problems in importance. Indeed, it may lead to discoveries bearing on the nature of gravitation itself. It has long been known that the motion of the moon is not in keeping with the theory. The observed positions of the moon are not in good agreement with the computed positions and since the theory has been carried to a high degree of accuracy it is now suspected that the difference is due to the action of some unknown law that may be as fundamental as the law of gravitation.

The positions of most of the members of the solar system can be computed over an interval of a number of years, according to the law of gravi-

tation, with such a high degree of accuracy that the observed and computed positions are practically identical. The same cannot be said of the moon, however. For half a century or a century the moon will revolve around the earth a little ahead of its regular rate and then for another long period of time will gradually fall behind. Empirical corrections are constantly being applied to the moon's position in order to bring the observed and predicted positions into agreement.

So complicated is the theory of the moon that only astronomers possessing the highest mathematical ability are fitted to cope with it. Noted mathematicians and astronomers have spent years of effort in trying to discover the cause of the large and continually increasing discrepancies between the predicted and observed positions of the moon.

New tables for computing the position of the moon have recently appeared. They are the result of years of work by Prof. E. W. Brown of Yale University, one of the best known theoretical astronomers of the present day, and a number of assistants. It is believed that these tables give the moon's position with as high a degree of accuracy as it is possible to obtain it by taking account of

all known factors affecting the motion of our satellite. Nevertheless, positions of the moon computed with the new tables do not agree with the observed positions, and it is evident that there is some unknown factor in operation that is affecting the motion of the moon.

Comparisons of the observed with the predicted times of beginning and ending of totality in total eclipses of the sun by the moon show the amount of error in the computed position of the moon at the time of the eclipse.

It was found in 1900 that the predicted time of the beginning of the total eclipse was seven seconds too early and the path of the moon's shadow upon the earth was consequently a mile or two in error. In 1905 astronomers were surprised to find the difference had increased to twenty seconds, and in the total eclipse of June 8, 1918, the predicted time would have been in error eighteen seconds if a correction had not been applied shortly beforehand, which reduced the amount of the error almost to zero.

This correction was found from recent observations of occultations of stars by the moon. Since the positions of the stars can be obtained with a

high degree of accuracy the true position of the moon can be found for the time when the star is occulted or hidden behind the disk of the moon. Observations of eclipses and occultations are used to correct the tables that are used to predict the moon's position from year to year, but these corrections are empirical and it is not known yet to what they are due.

It will be remembered that an unexplained error in the computed positions of Uranus finally led to the discovery of the planet Neptune, which was producing the deviations in the predicted places of this planet. The irregularities in the moon's motion cannot be attributed to an undiscovered planet, however, and there is a strong possibility that there may be something in the nature of gravitation itself that is producing the discrepancies.

According to a theory that has been recently advanced by Prof. See of the Naval Observatory at Mare Island, Cal., gravitation is to be considered as an electro-magnetic force. He believes that the unexplained deviations in the moon's position are caused by the refraction, dispersion and absorption of some of the magnetic forces of the sun by the earth at the time of full moon and more especially

at the time of the eclipse of the moon by the earth. It appears that this explanation may account for one of the unknown terms but it does not account for all of them.

It may happen that when the cause of the errors in the moon's computed positions is found a fundamental law of the universe will be discovered as well. It is in just this way that many valuable and important discoveries are made. The velocity of light was discovered while attempts were being made to explain errors in the computed times of the eclipses of Jupiter's satellites. Bradley made several very important discoveries, such as the aberration of light and the nutation or wabbling of the earth's axis that affects the positions of all the stars, while he was attempting to measure the distances of the stars. So it will be by no means surprising if our troublesome little moon some day figures in a very far reaching discovery.

The moon's attraction for the earth gives rise to the tides so familiar to every one. The sun also produces tides upon the earth, but as the sun is so much further away its tide raising forces are inferior to those of the moon.

A small amount of light and heat is reflected

from the moon to the earth and there are minute variations in the position of the magnetic needle to be attributed to the moon's influence, as well as some minor changes in the earth's motion. Aside from this the moon does not affect in the least conditions existing upon the earth, though there is no other heavenly body that is associated with more superstitious beliefs.

To follow the course of the moon through the heavens during one month, the period of its revolution around the earth, and to explain the cause of its various phases is a very elementary matter, yet it appears to be a most perplexing problem for nearly every one. In the present age, when astronomical knowledge is so easily obtained, artists still delight in placing the crescent moon overhead at midnight, an astronomical blunder as serious as picturing the sun in the west early in the morning. Less frequently the horns of the crescent moon are turned toward the horizon, though a moment's thought would demonstrate the absurdity of this position if the cause of the moon's phases is at all understood. A most woeful lack of knowledge, either of the cause of the phases of the moon or of the relative distances of the stars and the moon,

is evidenced when a star is pictured between the horns of the crescent moon.

A knowledge of the elementary facts concerning the moon and its motion is as easily acquired as is the knowledge of the cause of the rising and setting of the sun and the changing seasons, and it seems quite unbelievable that there should be widespread ignorance of such simple, yet fundamental, matters.

CHAPTER XII

SHOOTING STARS AND METEORS

UNTIL the beginning of the nineteenth century it was deemed an absurdity to believe that stones fell to earth from the heavens. Such rumors had persisted for centuries, but they were attributed to the ignorant and superstitious.

Finally, in the year 1803 man was compelled to change his views somewhat suddenly; not in some far away corner of the earth, but over an extent of many miles in thickly populated districts of France thousands of such stones fell in a single day. Their appearance was accompanied by the sharp reports and detonations now known to be always attendant upon the passage of meteorites through the earth's atmosphere.

Scientists sent to the district by the French Institute heard accounts of the phenomenon as seen

by hundreds of eye witnesses and brought back many of the stones.

After man's mind was open to conviction it was found that the fall of meteoric stones from the heavens was by no means a rare occurrence, though their appearance in such large numbers as had been observed in France in 1803 was unusual. It has been concluded from a conservative estimate that the number of large meteorites or aerolites that reach the earth yearly must approximate fully one hundred in number.

This estimate includes also those that fall in uninhabited lands or into the large bodies of water that cover three-fourths of the earth's surface. In addition to the meteorites that weight anywhere from a few pounds to several tons, it has been estimated from extensive observations that between ten and twenty million meteors or shooting stars enter the earth's atmosphere daily. Their average weight is considerably less than an ounce and they are usually consumed by the friction produced by their rapid flight through the air. The resulting dustlike particles float in the air or gradually settle to the earth's surface, adding to its mass a few tons daily.

Though this seems to be a considerable amount, it is so small in proportion to the earth's total mass that it would not become appreciable for many hundreds of thousands of years. These meteors are believed to be the débris of comets encountered by the earth in its journey around the sun. If the earth is continually encountering meteoric dust, so, doubtless, are all the other planets as well, and the total amount within the solar system must be very considerable.

Astronomers are now giving a good deal of attention to the question of the scattering of light by cosmical dust throughout the universe at large and there are indications of the presence in our own solar system of appreciable quantities of finely divided matter.

Interplanetary space is by no means a void. Tails of comets appear at times to be brushed aside or cut off in a manner quite unaccountable, unless we assume that some resisting medium has been encountered such as would present no difficulty to a larger mass, satellite or planet, but becomes very disturbing to such tenuous matter as the tails of comets.

The motion of Mercury is not just as it would be

if affected only by the attraction of the known planets. This has led to the suspicion that there may be one or two small intra-mercurial planets, and they have been searched for diligently at times of total eclipse of the sun, so far unsuccessfully. Some astronomers believe, however, that finely divided particles of matter existing in the Zodiacal Light may account for the peculiar behavior of the innermost planet.

After sunset in the spring or before sunrise in the fall, when the ecliptic rises most sharply from the horizon, the careful watcher may see a faint wedge of light, about equal in brightness to the Milky Way, extending from the horizon to the zenith. Near the horizon it is fully twenty degrees wide, but it rapidly narrows to a width of three degrees or four degrees overhead. Under favorable conditions it can be traced far beyond the zenith. This is called the Zodiacal Light and exactly opposite the sun also appears at times a faint oval patch of light covering an area about the size of the bowl of the Big Dipper. This is the Counter-glow, and it is so excessively faint that few have ever observed it.

Both Zodiacal Light and Counter-glow are un-

observable if there is any moonlight. It is believed that the Zodiacal Light is due to reflected sunlight from a great number of finely divided particles circulating around the sun in the plane of the earth's orbit and extending even beyond the earth. The Counter-glow is not so easily explained, but it probably represents a condensation of these particles at some point beyond the earth's orbit at a point about 930,000 miles from the earth and just beyond the reach of its shadow where the combined forces of the earth and sun would cause matters to be drawn into a sort of whirlpool of motion. Sunlight shining upon these particles makes them visible to us when directly opposite the sun.

So it appears that cosmical dust and fragmentary matter is fairly plentiful within our solar system. Probably a large amount of such meteoric dust is swept up by the larger planets as they journey around the sun, but the supply is also replenished by the escape of particles of matter from the atmospheres of sun and planets.

The sun is the seat of intense activity and explosive agents are at work there that cause flames of the lighter gases to shoot forth at times to

heights of more than 300,000 miles with velocities of about two hundred miles or more per second. A velocity of more than three hundred and eighty miles per second would enable particles of matter to permanently escape from the control of the sun and pass to space beyond. Light pressure acting upon small particles of matter may also overbalance the sun's attraction and drive cosmical dust away from the vicinity of the sun. The corona, we know, is partly composed of dust particles and liquid globules shining by reflected sunlight as well as light of incandescence.

Most interesting of all fragmentary matter existing within our solar system are the meteorites previously mentioned. There are several theories concerning the origin of these peculiar stones. The idea that they are simply larger portions of disrupted comets is quite generally held, and yet these stones rarely appear when showers of meteors are experienced. They almost invariably appear singly.

The fact that they contain no unknown elements and in some respects resemble lava from deep volcanoes led to the old belief that they were expelled from the interior of the earth or other planets by

intense volcanic activity in the past and after receding to great distances returned and fell once more within reach of the earth's attraction. This belief leaves unexplained many of the characteristics of meteorites. Volcanic action intense enough to overcome the effect of the earth's attraction would cause a fusion of the material of which the meteorites consist such as does not appear.

In some few instances meteorites are composed of nearly pure iron, but usually they are fragments of stone with peculiar crystals and considerable quantities of gases that are sometimes combustible, hidden in their crevices. They usually show none of the results of the action of water and very little oxidation. Some show veins where foreign substances have been slowly deposited and signs of fracture and sliding of one surface on another.

The most interesting theory respecting these visitors from the heavens is that they are fragments of disrupted bodies, possibly of planetary dimensions, that at some time chanced too near a larger mass and were torn asunder under tidal stress and strain.

It is even a possibility that the solar nebula,

from which we believe our present solar system was fashioned, originated in the close approach of two suns and that around one or both of these suns at that time planets were circling. The tremendous tidal reaction between the two suns would result in streams of matter being ejected and the formation of a spiral nebula.

If planets encircled these suns they would be completely shattered and scattered as meteoric fragments. The larger nuclei of ejected matter would gradually increase in size by sweeping up other fragments of matter and become the chief planets of another system. Smaller nuclei in the vicinity of larger ones would form the satellites attendant upon the planets. The eight hundred or more asteroids may represent smaller independent masses that have avoided collisions, while comets and meteors are the débris remaining when order has finally been brought out of chaos.

During the course of millions of years all fragments of considerable size would be captured by the major planets and satellites. In fact, the scars on the face of our satellite, many believe, are due to terrific meteoric bombardment in the past. According to this latest theory of the possible origin

of meteorites, fragments of worlds antedating our own may fall to the earth's surface every year by scores, and in a few cases find their way into our museums.

CHAPTER XIII

OUR CELESTIAL VISITORS, COMETS

THE number of comets that are observed and recorded is enormous, but most of these are telescopic and conspicuous comets are few. Hardly a year passes without the appearance of several of these mysterious visitors. Some of these comets are old friends returning, periodic comets that arrive more or less on schedule time, while others that travel in greatly elongated ellipses only approach the sun once in hundreds or even thousands of years. Donati's great comet of 1858 takes 2,000 years to complete its circuit. It is a question whether some comets ever return to the solar regions again, for their orbits appear to be parabolic rather than elliptical. Since, however, we can observe only a very small portion of the orbits of some comets that penetrate far into the depths of

space beyond the orbit of Neptune and since the arc of both ellipse and parabola are nearly coincident for the short interval of observation we are left in doubt as to whether all comets return or not.

Some may speed forth into the immensity of space that separates our solar system from the stars beyond never to return, but there are comets in great numbers that are known to be permanent members of the solar system, and that accompany it on its onward journey through space. They encircle the sun in orbits that are greatly elongated ellipses markedly different from the nearly circular orbits of the planets.

If a comet on its journey around the sun passes close to one of the major planets, it may come under the gravitational influence of that planet to such an extent that its path will be entirely changed and its aphelion or the point of its orbit furthest away from the sun will afterward lie close to the orbit of that planet. Jupiter has a family of about thirty comets. His family is the largest because his mass is greater than that of all the other planets combined. All the aphelia of these captured comets, of course, lie near Jupiter's orbit. Neptune has a family of six comets.

There are two or three groups of comets whose aphelia lie at distances several times as great as Neptune's distance from the sun, and possibly future investigations of cometary orbits of long period may lead to the discovery of several trans-Neptunian planets. There is no reason to suppose that Neptune is the farthest planet from the sun, for the gravitational influence of the sun extends enormously beyond it.

Comets of short period are usually spoken of as periodic comets. The shortest period, three and one-third years, is that of Encke's comet, which, when furthest from the sun, never gets beyond the orbit of Jupiter, while Halley's noted comet, which made its last return in 1910, has the longest period of comets classed as periodic. No great or conspicuous comet belongs to this class.

Though comets are the bulkiest of all heavenly bodies, they are also possessed of the least mass of any known bodies that travel through space. Comets usually consist of a nucleus, coma or head, and tail. The nucleus, which in great comets frequently appears as bright as first magnitude stars, is no more than a swarm of meteoric particles. Of the actual size of the particles we can form no

idea, but they are evidently held together by a very loose bond of gravitation. The entire nucleus is enwrapped in a gaseous envelope that forms the head of the comet. This coma or head is often of enormous dimensions. The head of Donati's comet was 250,000 miles in diameter, while the head of the comet of 1811 measured over 1,000,000 miles at one time. As the comet approaches close to the sun the head is observed to contract or diminish in size.

The tail, which is the most noticeable and distinctive feature of a comet, does not develop until it draws in toward the sun. It then becomes, in many cases, millions of miles in length. The Great Comet of 1843 had a tail more than 200,000,000 miles in length and the comet of 1882 had a head 200,000 miles in diameter and a tail 100,000,000 miles long. These two comets, as well as the great comet of 1880, pursued nearly identical paths. All three were noted for their close approach to the sun. The comet of 1843, in fact, passed through the corona and within 32,000 miles of the sun's surface, and only its enormous velocity of several hundred miles per second saved it from actually falling into the sun. Its enormous tail appeared

BROOKS' COMET
(Photographed by Barnard at the Lick Observatory)

to be whirled around the sun in about two hours and this fact proved conclusively that the tail could not be an actual appendage, but must be a series of emanations from the head due either to the electric repulsion of the sun acting upon highly rarefied material in the head of the comet or to light pressure which overbalances the effect of gravity in the case of particles of extremely small mass.

Comets shine not only by reflected sunlight, but by inherent light as well, and the spectroscope shows that they are composed chiefly of gaseous compounds of hydrogen and carbon, though when near the sun metallic lines of sodium and iron frequently appear. So highly rarefied is the material composing the heads and tails of comets that faint stars are often observed to shine through them undimmed, even when close to the nucleus. The fact that the earth has many times been involved in the tails of comets with no disastrous consequences—in fact, without our knowing it until later—shows the flimsy nature of these appendages. If the earth should meet a comet head on, however, it would doubtless experience a more or less severe meteoric shower, depending upon the size of the meteoric stones within the nucleus.

Continued returns of periodic comets to the vicinity of the sun tend to reduce them greatly in size and brilliancy and it is for this reason that none of the short-period comets are as striking or conspicuous objects as the great comets of long periods and infrequent returns. Even Halley's comet, the largest and most noted of periodic comets, was a decided disappointment as a "show" comet upon its return in 1910. Meteoric showers are composed of the débris of comets that have become disintegrated, and comets have been seen to separate into two or more branches. Many comets travel in groups along the same curve. The great comets of 1843, 1880 and 1881 belong to such a group. They follow practically the same path and may have even formed one enormous comet at some time in the past.

It is not so many years since the visits of these mysterious strangers were received with dread and fear, for it was believed that they predicted evil, either war, famine, pestilence or death of royalty. Needless to say, such fears were entirely without foundation, but so superstitious are the masses that even to the present day traces of these beliefs still linger. In 1910 when Halley's comet made its

predicted return, Chinese mobs attempted to frighten away the unwelcome visitor with flaring torches. If a great and conspicuous comet had made a sudden appearance just prior to August, 1914, we might have found that "civilized" western nations, even in this age, are not so entirely free from superstitious fear concerning unusual heavenly phenomena as we might like to believe.

CHAPTER XIV

HOW CARBON DIOXIDE IN THE EARTH'S ATMOSPHERE AFFECTS CLIMATE

ACCORDING to the scientists, man's extravagant consumption of coal may, in the course of a very few centuries, materially affect the composition of the atmosphere and thereby the average yearly temperature at the earth's surface and climatic conditions.

Carbon dioxide, which is the product of the combustion of coal, is one of the constituents of the atmosphere. The amount of this compound found in the atmosphere is extremely small, three-hundredths of one per cent. by volume, five-hundredths of one per cent. by weight. Although the percentage of carbon dioxide is so small it has an appreciable effect upon the earth's climate.

The amount of coal mined and burned annually

is approximately one billion tons, and as a result of this combustion a little over three and a half billion tons of carbon dioxide are added yearly to the present amount of carbon dioxide in the earth's atmosphere, which is approximately three trillion tons.

A simple computation will show that the amount of carbon dioxide in the atmosphere will be doubled in about eight hundred years if the present rate of combustion of coal is maintained.

The absorbing properties of carbon dioxiae are practically the same as those of water vapor. The intensely hot rays of the sun of shortest wave length, those from the blue end of the spectrum, pass through the carbon dioxide and water vapor in the air as readily as through nitrogen and oxygen, the chief constituents of the atmosphere, but the longer heat rays, as they are called, from the red end of the spectrum suffer strong absorption by the carbon dioxide and water vapor in the earth's atmosphere.

The radiations from the earth's surface are composed almost entirely of the rays of longer wave lengths and are, therefore, largely absorbed by these compounds. The blanketing effect of the at-

mosphere is greatly increased by the presence of water vapor and carbon dioxide. It has been estimated that fully thirty-five per cent. of the sun's rays that enter the atmosphere of the earth perpendicularly are absorbed before they reach the surface of the earth.

At night the heat absorbed by the atmosphere during the daytime is radiated in all directions and portions of it strike the earth's surface directly and warm it, while other portions are reflected back to the earth from the upper atmosphere. Also the heat rays radiated from the earth's surface during the night are trapped by the water vapor and carbon dioxide in the atmosphere and raise the temperature of the air.

As a result the extremes of temperature between day and night are greatly reduced by the presence of these two compounds in the atmosphere.

Every one is aware of the fact that on the mountain heights where the atmosphere is less dense the days are hotter and the nights colder than they are at sea level. It is also well known that the early autumn frosts occur only when the air is clear and the amount of water vapor in the atmos-

phere small. An increase in the amount of carbon dioxide in the air would have the same effect on the temperature as an increase in the amount of water vapor, since the heat absorbing properties of the two are the same.

Certain geologists believe that the amount of carbon dioxide in the earth's atmosphere has varied periodically over long intervals of time and that the glacial periods and the warm periods that have occurred alternately in the past have been due to this variation in the composition of the atmosphere. The effect of an increase in the amount of carbon dioxide in the earth's atmosphere is to increase the general temperature of the air, while a decrease in the amount of carbon dioxide lowers the surface temperature of the earth.

The enormous amount of coal burned by the human race yearly will, therefore, in the course of time, increase the earth's temperature and affect the climate throughout the world. Whatever affects the nature or direction of the air currents that flow over the earth's surface will possess the greatest influence over the general temperature of the world, for to the air currents and their equalizing effect upon the climate is to be attributed the

habitability of both the polar and tropical regions of the earth.

The composition of the atmosphere has the greatest influence over the forms of life existing upon a planet, and in considering the question of life on other planets the nature and composition of the atmosphere is first in importance.

It is extremely difficult to speculate concerning the forms of life one would meet on Mars or Venus until we know something definite about what elements and compounds occur in the atmosphere of these planets and in what proportions. Even small variations in the amount of carbon dioxide in the earth's atmosphere can seriously affect its climate. A slightly greater percentage of this compound in the atmosphere of Mars might go far toward overcoming the greater extremes of temperature between day and night arising from a rarer atmosphere and greater distance from the sun.

Then, too, the relative amounts of nitrogen and oxygen in a planet's atmosphere would have to be taken into consideration in speculating on the possibility of the existence of red-blooded organisms that require a large percentage of oxygen for their development.

The elements that enter into the composition of the earth's atmosphere and the percentage of these elements in a given volume are: Nitrogen, seventy-eight per cent.; oxygen, twenty-one per cent.; argon, ninety-four hundredths of one per cent. There are, in addition, extremely small amounts of krypton, helium, neon, xeon and other rare elements. The amount of water vapor in the air is, of course, variable and can never exceed a certain amount, and the amount of carbon dioxide, as we stated before, is only three-hundredths of one per cent.

There are in addition to these elements and compounds a number of impurities, such as ammonia, soot and dust particles that occur in extremely small amounts as a rule. We might also include the poisonous gases and compounds that man has employed during the present war, though their sum total is infinitesimal and probably surpassed in total volume by the gases arising from a single volcanic eruption.

The height of the earth's atmosphere can be determined by observing the flight of shooting stars or meteors and the altitude of the auroral streamers from two different positions on the earth's sur-

face, observations being made simultaneously at the two stations, or it can be determined from the duration of twilight. The results vary according to the method used, since the density of the atmosphere decreases rapidly with increased distance from the earth and the different phenomena occur at different densities.

The atmosphere extends fifty miles above the earth in quantities sufficient to produce twilight. It has been found that it is sufficiently dense to offer resistance to meteors at a height of 100 miles from the earth. The southern ends of auroral streamers are usually more than 100 miles in height; and they sometimes reach a height of 500 miles.

The auroræ are electrical phenomena of the rare upper atmosphere and the density required for their display is very slight. It is usually considered that the atmosphere does not occur in appreciable amounts to more than 100 miles from the earth's surface.

The weight of a column of air reaching from the earth's surface to the limits of the atmosphere and one square inch in cross section weighs fifteen pounds, and from the known area of the surface of

the earth it is possible to find the weight of the earth's atmosphere, which is approximately six quadrillion tons, or one-millionth of the mass of the earth.

CHAPTER XV

HOW A LITTLE SPECTROSCOPE TELLS THE SECRET OF LIGHT

IT IS rightly considered one of the greatest achievements of science that a tiny ray of light coming to us from the immeasurable depths of space can be made to unfold the secrets of the composition and nature of the body from which it emanates, whether it is gaseous or solid, highly heated or comparatively cool, new or far advanced in evolution, and even the amount and direction of its motion.

The little instrument that accomplishes such wonderful results is known as the spectroscope and the field of study that it has opened to us is known as spectrum analysis. The essential part of the spectroscope is simply a glass prism, or chain of prisms in some cases, or it may be a piece of plane

glass or speculum metal closely ruled with fine lines, sometimes as many as 20,000 lines to the inch, known as a diffraction grating. In each case the object is to separate white light into the various colors that enter into its composition. When a ray of white light such as sunlight is passed through a transparent medium denser than air, such as glass or water, it is split up into its component parts, which are rays of different colors and wave lengths. We have then what is known as the spectrum. This principle we have all seen illustrated in the rainbow, which is formed when rays of white light or sunlight pass through falling drops of water, which act as tiny prisms and split white light into the rays of different wave lengths and color that compose it. All the colors of the rainbow are familiar to every one and they are the colors of the spectrum. If, as in the spectroscope, a ray of sunlight is passed through a glass prism we see a ribbon of variegated colors blending into each other gradually. If the prism is so turned that the red will appear at our left hand we shall see in order from left to right—red, orange, yellow, green, blue, indigo and violet, arranged according to their respective wave lengths. The red rays have the greatest

wave length and are the least bent from their course and the violet are the shortest and so the most refracted. The wave lengths of the visible spectrum vary from .0008 millimeter for the red to .0004 for the violet. When we consider that .0001 millimeter is equivalent to 1-250,000 of an inch and that we can measure a displacement of this amount in the spectrum the wonderful accuracy of measurements by this method is apparent.

Beyond the visible red rays we have the "infra red" rays and beyond the violet rays the "ultra violet" rays. The human eye is not sensitive to these colors, but their presence has been detected by photography, in the case of the ultra violet rays, and by the heat produced by infra red rays, which are sometimes spoken of as "heat rays." The photographic plate is particularly sensitive to the violet end of the spectrum. Very much can be accomplished in spectrum analysis by means of the photographed spectrum.

An examination of the spectrum produced by a ray of sunlight, which is known as the solar spectrum, shows a great number of fine dark lines crossing the solar spectrum vertically. These are the absorption lines. sometimes called the Frauen-

hofer lines, and it is these dark lines that tell us so much of the temperature and constitution of the sun.

Every chemical element when heated to vaporization and every gas heated to incandescence has its own characteristic spectrum, certain bright lines that essentially belong to it alone and that always appear in exactly the same position in the spectrum. The greater the heat the more intense the lines appear, so the spectroscope can detect temperature changes. No two elements can have the same lines in the spectrum nor any lines in common. When a compound of sodium, for instance, is heated to vaporization, two lines characteristic of sodium appear in the yellow of the spectrum always in exactly the same position. They are the characteristic lines of sodium, and if they appear in the spectrum of a certain star we know that sodium occurs in that star in a state of vaporization. If, however, a still hotter source of light is placed behind the vapor of sodium so as to shine through it the sodium lines appear as dark lines in the spectrum of the hotter light. Any other element, of course, acts in the same way when placed before a brighter light and the dark lines of the

substance are then spoken of as absorption lines. Take away the source of light beyond and they appear as bright lines again.

The dark lines that appear in the solar spectrum are the lines of vaporized elements that surround the hotter surface of the sun, and it has been through comparison of these lines with the bright lines produced by known terrestrial elements in the laboratory that we have found that the sun contains many elements that occur on the earth. It is an interesting fact that at the time of total solar eclipse, after the surface of the sun has been entirely hidden by the moon and before the surrounding gaseous envelope has been covered, the dark lines of the solar spectrum suddenly flash forth as bright lines. This is what we should expect, for when the hotter source of light beyond is removed, the absorption lines appear as the bright lines of vaporized elements shining by their own light.

There is a principle of spectrum analysis the value of which can hardly be overestimated in connection with the study of the heavens, for it has opened an entirely new field of discovery only secondary in importance to that opened up by the discovery of the telescope. That is, if a body emit-

ting light, such as a star or nebula, is in motion either toward us or from us, this motion will show in its spectrum. If the body approaches us the wave lengths of the ray of light entering the spectroscope are of greater frequency and therefore shortened in length and all the lines of the spectrum show a shifting toward the violet end of the spectrum, and if the body is receding from us the wave lengths are of less frequency and, so, longer and all lines are shifted toward the red end of the spectrum, and the amount of the shift measures the velocity of the motion. This fact enables us to confirm the time of rotation of different portions of the sun's disk formerly determined by means of sun spots. It also tells us that the stars are moving and that the motion of a star in the line of sight varies from a few miles a second to over 200 miles a second in extreme cases. It is not usual, however, to find stellar motions greater than forty miles a second in the line of sight though the actual motions may be considerably greater. It shows the great accuracy of these measurements that stellar motions as small as one-fifth of a mile a second can be detected. The surprising fact has been indicated by the spectroscope that the stars least

advanced in evolution move the most slowly, and as the age of the star increases the velocity increases. A star starts in the beginning with hardly any motion and acquires increasing velocity. It is now generally believed that stars form in the regions of the Milky Way and as their velocity increases they move further and further away from this plane.

We can no more than touch upon a few of the many wonderful truths revealed to us by the spectroscope. Stars have been grouped into classes according to their spectra. There is the Orion type, often called the Helium type from the prominence of the lines of that element in the spectra of such stars. The Sirian type, named after its most prominent member, Sirius, shows hydrogen lines in great intensity. The Calcium type, named from characteristic lines of calcium, shows intense hydrogen lines as well. The Solar type, which includes our own sun, has its spectrum crossed by numerous dark metallic lines such as appear in the solar spectrum, and also hydrogen lines. In the type called K, which is next in evolution, the hydrogen lines have become fainter than some of the metallic lines. In the type last in evolution, composed of

dark reddish stars and known as type M, the spectrum is characterized by flutings due to titanium oxide. It is considered very remarkable that spectra of this type are so dominated by this one substance. These types have been named in the generally accepted order of evolution; a star may pass in its life through all these different stages. Earlier than the Orion stars occur, however, stars of type O, called Wolf-Rayet stars, whose spectra consist of bright bands on a faint, continuous background. These latter stars are all found in the plane of the Milky Way and at great distances, and are believed to come first in evolution. The great Andromeda nebula shows a spectrum, in which most of the lines of this type are present.

The Orion and Sirian stars, which come early in evolution, are blue-white and white stars. The solar type includes the yellow stars and the later types the reddish stars.

In the study of our own sun, pressure, magnetism and radiation are all detected and measured by the spectroscope. Among double stars we are finding, by means of the spectroscope, an ever-increasing number that are so close together that they are beyond the reach of the most powerful telescopes,

but the shifting lines of the spectrum reveal the mutual revolution of the two components.

In this modest little instrument we possess a key to many mysteries of the heavens that would otherwise be forever beyond our reach. It is little wonder that the astronomy of the spectroscope is called the "new astronomy" and by its means we hope to obtain an ever-increasing knowledge of the universe.

CHAPTER XVI

SECRETS OF THE SUN REVEALED BY THE SPECTROSCOPE

PRACTICALLY all that man knows of the physical constitution of our sun, which is simply one of the stars, has been discovered through painstaking examination of several thousand fine dark lines in the solar spectrum, spoken of usually as the Frauenhofer lines.

These investigations have been carried on in connection with extensive laboratory experiments with the spectra of all the known elements found upon our planet.

Not only the nature and distribution of the elements that exist in the sun's atmosphere have been determined in this way, but a number of very important additional facts have been ascertained as well, such as the magnetic field existing in sun spots and the amount of pressure prevailing at

the sun's surface. All the various forms of solar activity are constantly being recorded in the lines of the solar spectrum and to interpret the evidence correctly is the duty of the astronomer engaged in solar research.

The solar spectrum consists of a continuous band of variegated color crossed vertically by an enormous number of fine dark lines, fully 14,000 of which have been mapped and their wave lengths determined with a high degree of accuracy.

It is, of course, the relative positions of these dark lines in the spectrum that are important and not the bright, continuous band of color upon which they are projected, and which owes its origin to the intensely hot solar core of incandescent gases under high pressure. The dark lines originate in the cooler solar atmosphere lying just above the visible solar surface and are in reality not dark except by contrast. Remove the brilliant background and they appear as bright lines. This is exactly what occurs at the beginning of totality at the time of a total eclipse of the sun when they produce what is known as the "reversed" or flash spectrum.

As the moon passes before the sun the solar surface is covered more and more until finally there

comes a moment when the last slender crescent of light disappears. The brilliant background has been removed and the portion of the solar atmosphere lying just above the surface of the sun at the rim shines forth by its own light. The lines of the spectrum that are usually black on a bright background are now brilliant against a background that is black. This phenomenon is visible at the eastern edge of the sun at the beginning of totality and at the western edge at the end and is referred to as the flash spectrum. It lasts but a moment, as this lower solar envelope, spoken of as "the reversing layer" since it reverses the solar spectrum at this time, is very shallow, and so is quickly covered by the moon.

It is possible to compute its depth from the known motion of the moon and the duration of flash spectrums and it is found to be about 500 miles. In this layer occur the dense metallic vapors that give the dark lines of the spectrum, which are called absorption lines because they absorb from the light beyond exactly the same rays of which they themselves consist. Since to each chemical element belongs always the same definite group of lines in the spectrum, unvarying in posi-

tion even under a wide range of temperature and pressure, it is possible to determine from the positions of the various lines the elements to which they belong. By producing the spectra of all the familiar terrestrial elements in the laboratory, by heating them to incandescence in various ways and passing their light through the spectroscope, it has become possible to measure and map the lines of all known substances and to identify them as far as possible with the lines of the same elements found in the sun's spectrum. Since the light from the sun's interior gives the continuous band of color it is the gases that compose the sun's atmosphere and not the sun's interior that are studied.

Thirty-eight terrestrial elements are known to exist in the lower solar atmosphere. These are chiefly the metallic elements and hydrogen and helium. Carbon occurs only in compounds and free oxygen has been detected with great difficulty. Titanium oxide is found in abundance in sun spots. Some of the heavier elements, such as gold and mercury, are missing, but this may be due to the fact that the heavier elements probably lie at a greater solar depth and therefore do not appear in a spectrum belonging to the higher levels.

It is a peculiar fact that none of the "negative" elements appear in the solar spectrum. The halogen group, including such elements as chlorine and bromine, the oxygen group including the important element sulphur and the nitrogen group are not to be found in the sun, though nitrogen appears in the form of cyanogen. The explanation has been offered that the spectrum of an element is sometimes entirely suppressed by a small amount of another element. The spectral lines of the non-metals are apt to be suppressed by the metallic elements. It is well-known that helium does not absorb the rays from the solar surface and does not give a dark absorption line, as in the case with all other known gases. This is in flat contradiction to one of the fundamental laws of spectrum analysis. This is simply another peculiarity of this very unusual gas. It occurs in abundance in the sun, however, and its characteristic bright yellow line is in the flash spectrum and can always be seen when the light of the photosphere is screened off.

Of the fourteen thousand dark lines of the solar spectrum that have been mapped, one-third are "telluric" lines originating in our own atmosphere

and are due to absorption of the sun's rays by gases in the earth's atmosphere, chiefly oxygen, carbonic acid gas and water vapor.

The origin of about six thousand of the solar lines is still undetermined or doubtful. Some of these are extremely faint. Of course, many of them may belong to a single element. There is great disparity in the number of lines belonging to the various elements. The spectrum of iron is represented by more than two thousand lines in the solar spectrum, calcium by about seventy-five and lead by only one. The work of identifying the lines of the solar spectrum is still going on and it is expected that all the doubtful and unknown lines will be traced to their origin before many years.

Changes in solar temperature and pressure register their effect upon the appearance of the lines of the spectrum. Motion of the source of the light toward or from the observer, as motion of the west limb of the sun toward the earth and of the east limb in the opposite direction due to the rotation of the sun on its axis, causes a shift of all the spectral lines toward either the violet or the red end of the spectrum, according to a well known law of spectrum analysis. The periods of the sun's ro-

tation, varying according to latitude, have been accurately determined from this shifting of the dark lines of the spectrum.

By special contrivance light can be reflected from the two limbs so that two spectra may be produced simultaneously, the one from one limb immediately above the one from the other. The effect of the sun's rotation can then be determined very accurately from the double displacement of the lines. The lines originating in the earth's atmosphere will not show this shift and can be readily identified at this time. Increase of pressure in the solar atmosphere will broaden the lines and shift them all slightly toward the red. The continuous spectrum that forms the background of the dark lines is due to the light coming from the sun's interior where the pressure is so great that the lines have probably been broadened until they coalesce.

Dark absorption lines at times become temporarily bright in the centre for all or part of their length. This is spoken of as reversal of the lines, and is due to a hotter source of light suddenly being thrown in front of a cooler gas. This frequently occurs when some solar eruption causes a sudden upheaval of low lying, highly heated gases.

It is often seen in the spectral lines of prominences.

At times double reversals of lines are seen, particularly of the sodium and magnesium lines. In such cases the bright line itself widens and a fine dark line appears in the centre. This appears to be due to large quantities of the vapor at great density.

The dark lines of the spectrum often appear displaced and distorted, due to a sudden upheaval of gases and outbursts of solar activity in the vicinity of prominences.

A most important effect frequently observed in the vicinity of sun spots is that known as the Zeeman effect. This is the splitting of a line into two or more components of opposite polarity, due to the presence of a magnetic field. It was from observing this effect that Hale discovered the magnetic field existing in sun spots. There is a whirling or vortical motion in sun spot regions carrying along electrically charged particles that produce the magnetic field. In fact, it has been found recently that the whole sun is in a magnetic field whose poles agree very closely with the sun's poles of rotation, and it is also possible that the earth

and sun may be in magnetic states as a result of their rotation and that all rotating bodies are magnetic.

It has been possible to touch upon only a very few of the most important facts that have been discovered from careful study of the dark lines of the solar spectrum made with that most valuable instrument, the spectroscope. The branch of solar physics is probably the most fruitful of all fields of astronomical research, and our knowledge of the nature of the sun and its surroundings is increasing rapidly.

CHAPTER XVII

THE SPOTS ON THE SUN

SUN spots appear singly and in groups in constantly recurring cycles upon the surface of the sun. Near what is known as the period of sun spot maximum, the photosphere or visible solar surface is never clear. It is often possible at such a time to count as many as fifty spots occurring singly or in groups. Large single spots are less frequent than groups consisting of a fairly large spot accompanied by a train of smaller ones. Spots vary greatly in size. Isolated spots frequently attain a diameter five times that of the earth, and sun spot groups at times cover an area of more than one-tenth of the sun's diameter.

The average duration of a sun spot is two or three months, though some last only a few days. They are carried across the solar disk from west

to east, and the average time it takes a spot to perform a revolution is twenty-seven and one-fourth days. Different spots show considerable difference in time of rotation, as we should expect, for the sun's period of rotation is not constant as is the case with the earth, but varies greatly for different solar latitudes. Spots, moreover, have slight motions of their own which affect their time of revolution. A spot is visible continuously for about two weeks, appearing at the western edge of the sun and disappearing over the eastern edge, to reappear once more at the western limb after two weeks have elapsed, provided it has not suffered dissolution in the meantime. Spots often appear and reappear for several successive solar rotations with no marked change of form.

At times a sun spot will form in a single day, again it will require days or even weeks for complete development. Usually there is disturbance of the solar surface for some time before the appearance of a spot. Many brilliant faculæ, which are intensely bright flecks upon the sun's surface, make their appearances, and among these are scattered very small, black dots which gradually enlarge. Between the black dots appear grayish

patches, which have the appearance of a veiled dark mass. This veil gradually fades away and we see the perfected spot. This consists of a dark central portion or umbra and an extensive grayish penumbra. The black dots either coalesce with the principal spot or disappear or go to form an attendant train of smaller spots.

When a spot is formed it is usually roughly circular in form and remains without marked change until it breaks up. When this occurs the surrounding solar surface seems to crowd in upon the penumbra and bridges of light that are often much brighter than the average solar surface span the umbra or dark central portions. The spot disappears as if overwhelmed and the disturbed surface is again covered with the brilliant flecks or faculæ which are regions of intensely high temperature. Frequently the disturbance breaks forth anew at the same spot after a few days' interval and another spot may appear exactly where the old one disappeared. This appearance and disappearance may be repeated several times. Occasionally a large spot divides into two or more and the parts seem to repel each other and fly asunder with a velocity that may reach as high as a thousand miles

THE GREAT NEBULA IN ORION

(Photographed by Ritchey with the 2-ft. reflector of the Yerkes Observatory)

an hour. This repulsion probably arises from the fact that a strong magnetic field exists in sun spots, adjacent spots frequently being of opposite polarity.

When a sun spot is forming, eruptive prominences appear in the immediate neighborhood. These are upshooting jets of gases that attain a height of 20,000 or 30,000 miles on the average. They are varied and beautiful in appearance and change in form with great rapidity, often at a rate of 100 miles a second.

Sun spots are confined to certain definite zones or belts upon the sun's surface. They are never found at the equator or poles. In fact, their appearance beyond forty degrees north and south of the equator is extremely rare. They usually appear between ten degrees and thirty degrees north and south latitudes, and in the long run appear as frequently in one hemisphere as the other.

The periodicity of sun spots is one of the most interesting and most puzzling facts concerning them. Within a period whose average length is about eleven years, sun spots go through a cycle of maximum and minimum appearance. At time of maximum spottedness the sun's surface is never free

from spots; at the minimum weeks may pass without the appearance of a single spot. Although the average cycle is eleven years, individual periods may vary greatly, running from seven to seventeen years in duration. Attempts have been made to show that a larger period of thirty-three and one-third years exists, of which the smaller periods are subdivisions. When we know the cause of the sun spot cycle we shall have advanced far in the solution of the mystery of sun spots and all their numerous allied phenomena.

Sun spot spectra have been extensively studied and much has been learned from this means of investigation. They show the presence of strong magnetic fields as well as a marked cooling of overlying gases, and the presence within spots of such compounds as titanium oxide and calcium and magnesium hydride. These compounds could only form at comparatively low temperature and it is assumed that sun spots are regions of cooler solar temperature of about 3,500 degrees C., as compared with 6,000 degrees C. for the remainder of the photosphere.

The presence of the compounds above mentioned gives the sun spot spectra their peculiar fluted ap-

pearance, which is also seen in the red type of stars. This is very significant when we consider that the red stars are the older and cooler stars. Are sun spots then one of the signs of the sun's advancing age? And will they increase in size and importance as the sun grows older?

Sun spots, it is now believed, are manifestations of some deep-lying disturbance that is of far-reaching importance. Many phenomena go through cycles of change in keeping with the sun spot cycle. Among these are magnetic storms and magnetic disturbances upon the earth which are closely dependent upon the sun spot period. Severe magnetic storms upon the earth occur at a time when the sun's face is strongly spotted, and displays of northern and southern lights are also most marked at this time. The general surface air temperature of the earth is lower by about a degree at the time of maximum spottedness of the sun.

One of the most marked effects of the sun spot cycle is the form of the solar corona, which is only visible at time of total solar eclipse. At the time of a maximum sun spot period the corona is an evenly developed halo surrounding the sun. At the sun spot minimum it shows equatorial stream-

ers that often extend to a distance of several times the sun's diameter, while on either side of the solar poles only short filaments of light appear. So decided are these changes in the form of the corona with the change in the sun spot period that the two types are spoken of as "the sun spot maximum corona" and "the sun spot minimum corona."

As to what causes these periodic outbreaks upon the solar surface we are still in the dark. Some astronomers believe they are caused by external influences such as periodic returns of swarms of meteors or returns of certain planetary configurations. Careful and long-continued observations seem to show that sun spots are rather the result of internal disturbances which cause a transference of solar matter from within outward in a cyclonic motion, which has been compared in form to that of whirling waterspouts at sea. The central stem forms the umbra and the outspreading gases the penumbra. There is a tendency for a vacuum to form in the centre of the whirl and into this is drawn the overlying gases, chiefly hydrogen.

The rapid expansion of gases as they approach the solar surface from within causes a sudden cool-

ing, which accounts for the comparatively low temperature in spots and the formation of such solids as titanium oxide and the hydrides of calcium and magnesium. These dissimilar substances, it is believed, give rise by friction to the magnetic field which is known to be a feature of sun spots.

It is hoped that continued solar research will make known in time the cause of these peculiar periodic disturbances that are so far reaching in their effect.

CHAPTER XVIII

SOLAR EXPLOSIONS

A MOST interesting discovery has been made within the past few years of the sudden, but rather infrequent, appearance at the surface of the sun of hydrogen "bombs," as they have been called.

These "bombs" are apparently violent explosions of highly heated hydrogen gas in regions of great solar activity. At times, according to Dr. Ellerman, of the Mount Wilson Observatory, who discovered them, they will follow one another like balls of a Roman candle at intervals of ten or twenty minutes. The duration of the explosion is usually about two or three minutes, more rarely five or ten minutes. The "bombs" generally appear on the edge or at one side of active sun spot groups that are developing and are composed of

many members. Repeated explosions often occur almost exactly in the same place.

The presence of the "bombs" is revealed by the appearance of two intensely brilliant narrow bands of nearly uniform width on either side of the dark absorption line of hydrogen that is associated with the higher solar atmosphere. The fact that the dark line itself is not interfered with nor any other of the absorption lines belonging to the various strata of the sun's atmosphere shows that the explosions occur considerably below the chromosphere, the lowest, densest layer of the solar envelopes, in which are to be found the majority of all the gaseous elements that compose the sun's atmosphere.

The area covered by the explosion is so small that the bombs can only be seen with a large solar image and under fine "seeing" condition. Dr. Ellerman first saw the two brilliant bands suddenly appear one on each side of the dark absorption line of hydrogen in September, 1915, while he was observing the dark line for distortions and reversals in connection with an active sun spot group.

Within two minutes the bright bands disap-

peared and were not seen again. A month later additional explosions were recorded visually and photographically.

The phenomenon of the solar hydrogen "bombs" has now been recognized for some time as an established feature of solar activity. The close association of hydrogen with sun spots in the form of vast eruptive prominences of highly heated hydrogen and the descent of cooler hydrogen from the upper solar atmosphere into the vortices of sun spots has long been known.

A most valuable instrument employed in studying the distribution of the various gases in the sun's atmosphere is the spectroheliograph, which is simply a moving spectroscope timed to travel over the solar disk at a uniform rate with the slit of the instrument so adjusted that the light from only one line of an element in the solar spectrum is admitted to the eye or the photographic plate.

In this way the distribution of the vapors of incandescent hydrogen or calcium, iron or any other element at different levels of the sun's atmosphere can be studied in great detail as well as the connection of these elements with sun spots and other solar phenomena. When the sun is viewed with

the spectroheliograph in the light of a single spectral line of hydrogen it is possible to detect the presence of the flames of incandescent hydrogen in the prominences by their projection on the sun's disk as irregular dark patches or streaks as well as to study their infinite variety of forms when the slit of the instrument is set at the edge of the sun's disk.

When the surface of the sun is viewed telescopically, it presents a peculiar mottled appearance, or rice-grained structure, as it is called. The spectroheliograph shows that this same structure is found in the chromosphere and in the higher solar atmosphere. The rice grains of the sun's surface are intensely brilliant flecks of light, each composed of a great number of minute granules or mere points of light.

The rice grains are usually about 400 miles in diameter, while the granules measure less than ten miles across. In sun spots these minute granules are replaced by minute filaments that group themselves into the familiar "thatch straw" structure of the penumbra that surrounds the umbra or dark central portion of sun spots.

It is now believed that the granules and the fila-

ments are all the same. Columns of highly heated gases arise by convection from the sun's interior. The granules are cross section views of these vertical columns. In the vicinity of sun spots the ascending columns of gases are drawn into positions more or less at right angles to their normal positions by the whirling vortical motion existing in sun spot regions, and they then appear as the long, slender filaments that form the thatch straw structure of the penumbra of sun spots.

Now the spectroheliograph shows in the layers of the sun's atmosphere above the photosphere the same peculiar structure. The "flocculi" of hydrogen and calcium resemble in appearance the rice grains of the sun's surface. These flocculi are ascending columns of expanding and cooling hydrogen and calcium vapors that rise far above the level of the photosphere, or visible surface of the sun.

It is an interesting fact that different spectral lines of an element usually are associated with different levels of the sun's atmosphere. The element hydrogen, for instance, has lines in the red end of the spectrum and lines in the violet. The red rays of any element in the sun rise normally to a much

higher level than the violet rays, for the rays of shortest wave length, violet and ultra-violet rays are more liable to be trapped in the denser lower atmosphere of the sun, while the longer red rays escape.

By setting the spectroheliograph on the violet lines of hydrogen the distribution of hydrogen in the lower levels can be studied, and by setting on the hydrogen lines in the red the scarlet flames of incandescent hydrogen gas in the prominences that reach to heights of 100,000 or 200,000 miles above the photosphere can be exhaustively examined.

It is possible that there are rays of extremely short wave length in the sun's interior that never reach the photosphere, but are imprisoned far beneath, while the red, orange and green rays of the various elements escape readily to the surface and the higher atmosphere of the sun. As a result the sun presents a decidedly yellowish hue to the eye.

The calcium flocculi representing highly heated columns of calcium gas are bright flecks on a dark background, for they are at a higher temperature than the surrounding gases, which appear dark by contrast, but still higher up, where hydrogen alone persists, the hydrogen flocculi appear dark against

a bright background of diffused gases, for at the reduced temperature of the higher level the expanded and cooled hydrogen shows its presence by absorption.

Photographs of these upper regions taken with the slit of the spectroscope set on the hydrogen line characteristic of this elevation show most interestingly the peculiar distribution of hydrogen gas here. Irregular dark streaks projected upon the sun's disk show the presence of eruptive or quiescent prominences. Above sun spots or sun spot groups the hydrogen flocculi are curved either in clockwise or counter-clockwise direction, showing that a whirling motion of the hydrogen gas exists and that it is being sucked downward with a cyclonic motion into the umbræ of the sun spots that lie at the level of the solar surface.

The revelations of the spectroheliograph are, therefore, rich in information concerning the distribution and behavior of the gases that are found at the surface of the sun and in all the different layers of its atmosphere.

It pictures a sun of explosions, eruptions and ceaseless activity. Countless columns of highly heated gases of many elements rise to the surface

and penetrate in some instances even into the higher solar atmosphere, the lightest elements attaining the greatest heights, later to descend in cooler streams or cyclonic whirls to the photosphere and the sun spot regions.

CHAPTER XIX

SOME RECENT TOTAL SOLAR ECLIPSES AND THEIR VALUE TO ASTRONOMY

ECLIPSES as well as comets were always hailed in ancient times with dire misgivings, and even at the present day the uneducated and ignorant of all lands are not entirely free from fear and superstition regarding these celestial happenings. Up to a few centuries ago it was firmly believed that such phenomena heralded some ominous change and there are instances in history of abandonment of certain enterprises and even cessation of battles and a peace hastily concluded due to the sudden darkening of the sun's face. In modern times, on the contrary, we find scientists bending every effort to observe all total eclipses of the sun in whatever portion of the world they may chance to fall that they may extend their

knowledge of the wonderful physical constitution of our sun and its mysterious coronal halo. To obtain observations during a few fleeting moments many hardships have been undergone by eclipse expeditions. Many disappointments have also been experienced in connection with this work.

The French astronomer Janssen escaped from Paris in a balloon at the time of the siege of Paris in 1870, carrying the essential parts of his instruments with him for the purpose of observing the total eclipse of the sun visible that year in Spain and Africa, only to be defeated by clouds.

War as well as clouds has been the enemy of many an eclipse expedition. At the beginning of 1914 elaborate plans were well advanced in many lands for observation of the total eclipse of Aug. 21, 1914, visible in Europe from Norway and Sweden through Russia to Persia, with a duration of about two minutes. All the leading countries of Europe, Argentina and the United States sent eclipse expeditions to Russia in the neighborhood of Riga and Kiev. Many expeditions were in the field setting up complicated photographic and spectroscopic outfits and practising preliminary drills that all might go smoothly during the critical moments,

even as the armies of Europe were mobilizing for the greatest war in the history of the world. A few parties were successful in spite of war and generally prevailing clouds, but the majority were either turned back before reaching their destination or experienced extreme difficulty in returning to their homes. Several German observers were detained as prisoners of war in Russia. The Lick Observatory expedition was compelled to return by way of Moscow, Finland and Sweden instead of by way of Berlin and Paris, as was originally planned, while their instruments were kept in Russia for nearly four years.

The first American eclipse expedition ever formed was sent to Penobscot in the War of the American Revolution. The first total eclipse to be observed scientifically to any extent in North America was the eclipse of July 18, 1860. Three American observers, including Prof. Simon Newcomb, the noted American astronomer, penetrated to the banks of the Saskatchewan to observe this eclipse, while the astronomer, Gilliss traveled to Washington Territory by way of Panama for the same purpose, and was amply rewarded by excellent views of the solar prominences and the

corona. Another American expedition sent to Labrador was defeated by clouds. From that date to the present time American eclipse expeditions have been sent to the path of totality of every important solar eclipse, whether in Europe, Asia, Africa or South America.

The eclipse of the 8th of June, 1918, was a return of the total eclipse of May 28, 1900, so successfully observed by a large number of eclipse expeditions in the Southern States from New Orleans to Norfolk. After an interval of eighteen years, eleven and one-third days, which is spoken of as the eclipse Saros, the earth, sun and moon returned to practically the same relative positions in the heavens and all the circumstances of the previous eclipse are repeated except for the fact that the fraction of a day in the period causes the eclipse to fall 120 degrees westward of its former position, the amount of the earth's rotation on its axis in this interval of time. In consequence a different portion of the earth's surface is visited by each returning eclipse of a given series. The eclipse of May 17, 1882, lasting only one minute and a half, but observed with great success by many eclipse expeditions in Egypt on the banks

of the Nile, belongs to this same eclipse family. The next return of the eclipse of June 8 will fall upon June 19, 1936, and its path will extend from the Mediterranean through southern Russia and Asia to the Pacific coast.

Since the path of totality of the eclipse of June 8, 1918, passed diagonally across the United States from Washington to Florida, eclipse expeditions were sent to the central line from nearly all the leading observatories in the country. No foreign expeditions were in the field on account of the war and many American astronomers were unable to observe the eclipse for the same reason.

Since it has now become possible to study the solar prominences without the aid of total eclipses and since the search for intra-mercurial planets appears to yield negative results, scientific interest has centred of late years chiefly upon the elusive coronal light, its nature and its cause and the character of the peculiar unknown gas coronium of which it is largely composed. Much is to be expected from future investigations along this line, but progress is necessarily slow, for so faint is the coronal light that the least percentage of direct sunlight completely masks it. So it is only when

the friendly moon interposes between the earth and sun and completely hides the solar surface that the beautiful pearly radiance of the corona may be seen.

According to the reports of astronomers who observed the eclipse highly satisfactory results were obtained by many of the eclipse parties stationed between Washington and Kansas despite the fact that clouds gathered all along the path of totality within the United States. The success of the majority of the expeditions is to be attributed to breaks in the overhanging clouds occurring just at the critical time.

According to the report of Prof. W. W. Campbell, director of the Lick Observatory, who was in charge of the Crocker eclipse expedition at Goldendale, Wash., observers at this station were preparing to accept complete defeat from dense clouds that overspread the sky from midnight of June 7 to past midnight of June 8, when within less than one minute of total eclipse a sudden break in the clouds uncovered an intensely blue strip of sky and the thin solar crescent. The entire eclipse programme was most unexpectedly carried out with complete success.

Less than one minute after the end of totality clouds once more covered the scene of the phenomenon. The "seeing" at the critical time was magnificent and the expedition became almost by a miracle the most successful expedition ever sent out from the Lick Observatory.

Twenty-six excellent photographs of the corona were taken at Goldendale, ten with the forty-foot camera on a large scale and eight each with a forty-eight-inch coronal camera of three-inch aperture and an eleven-inch coronal camera designed for landscape work. The last two cameras were suitable for showing the general outline and form of the corona and the extent of the streamers. The longest coronal streamers recorded at Goldendale were approximately three solar diameters, or two and one-half million miles, in length.

Six spectroscopic instruments mounted on a single polar axis registered valuable spectra of the corona and prominences, as well as of the chromosphere or lower solar atmosphere.

The corona was particularly beautiful in form, belonging to the variety known as a "petal-formed" corona, a type occasionally noted in past eclipses. The "petals" are the result of rifts in the coronal

streamers and the crossing of curved rays. Seven distinct petals were noted in the June eclipse.

Many observers described the corona as unusually brilliant and of an intense blue-white color. In shape it was roughly triangular, the long streamers to the east of the sun forming the apex and the more evenly distributed streamers to the west the base of the triangle.

The spectrum of the inner corona was "continuous," that is a continuous band of variegated color with no dark absorption lines, showing that it shone by its own inherent light and not by reflected sunlight. The outlying portions of the corona showed the faint absorption lines of the solar atmosphere and therefore it was evident that part of its brightness was due to reflected light from the sun.

At least five unidentified bright lines were found in the coronal spectrum and their wave-lengths were measured, while the existence of seven other bright coronal lines was suspected. The nature of the element or elements connected with these lines is undetermined, though several of the lines doubtless belong to the unknown element coronium.

The wave-length of the characteristic green line

of coronium was accurately measured from spectroscopic observations obtained during this eclipse, which will aid greatly in its future identification.

The chromosphere, appearing as an extremely narrow orange-colored rim of light surrounding the sun and composed of incandescent gases of many metallic elements, contrasted beautifully with the pearly light of the corona tinged with the green rays of the unknown coronium whose nature astronomers are most anxious to discover from observations obtained during total eclipses of the sun.

Rising from the chromosphere are usually seen during totality a number of "prominences," upshooting flames of incandescent hydrogen gas of a deep scarlet hue. These outbursts of incandescent gases from the dense lower strata of the solar atmosphere are at times very conspicuous and add to the weird beauty of this unusual scene.

Even to the unaided eye the prominences of June 8, 1918, were a most beautiful feature of totality. Three huge blood red prominences, varying from 45,000 to 60,000 miles in height, were visible 120 degrees apart. Though they were not higher than the average, their structure was extremely interesting. One of these on the west edge

of the sun was likened to the skeleton of some prehistoric monster. A number of other minor prominences were visible, and the north and south poles of the sun chanced to be marked by two bright prominences.

Several of the prominences were capped in a most peculiar manner by curved coronal rays resembling Gothic arches. The apexes of several of these arches lay at a distance of fully 200,000 miles above the solar surface. There appeared to be some connection between the coronal arches and the prominences. Doubtless the same force that caused the upheaval of the gases composing the prominences also produced the peculiar coronal caps above them.

The coloring of the solar surroundings during totality of the June eclipse has been described by those who were privileged to observe it as gorgeous beyond description. The deep orange tinge of the chromosphere, contrasting with the intensely brilliant blue-white light of the coronal rays curved into beautiful petal-like formations, and the huge blood red prominences presented a weird effect never to be forgotten.

The great value of the next total solar eclipse,

that of May 29, 1919, lay both in its extraordinary duration, amounting to nearly seven minutes at maximum and far exceeding the average totality of three minutes, and also in the fact that the eclipsed sun was to be in a field particularly rich in stars, midway between the Hyades and the Pleiades, a position unusually favorable for testing the new theories bearing on the nature of light and the influence of the sun's gravitational and magnetic field upon the path of a ray of light.

The belt of totality in this eclipse started on the western coast of South America, the boundary between Chile and Peru falling nearly on the central line, and the northern limit of totality passing only a few miles south of the Harvard College observatory station at Arequipa, Peru.

Here the sun rose partially eclipsed, so it was not expected that valuable observations would be obtained with the sun so close to the horizon. Passing over the towns of La Paz and Trinidad in Bolivia, the path of totality entered Brazil, crossed to the Atlantic Ocean at a point about three degrees south of the equator, passing almost centrally over the towns of Caxias and Sobral, where the duration was to be over five minutes, and then

crossed the Atlantic Ocean to Cape Palmas, Liberia.

At St. Paul's Rocks in mid-Atlantic, at latitude one degree north and longitude thirty degrees west, the total phase was to last more than six minutes. Bending southward from Liberia the path of total eclipse passed over Ile Principe, or Prince's Island, in the Gulf of Guinea, and Libreville in the French Congo; thence across the African continent to the Indian Ocean, the sun setting partially eclipsed over the island of Madagascar.

British astronomers organized two eclipse expeditions to observe this eclipse. Both expeditions were equipped at the Royal Observatory at Greenwich and left England about the middle of March, one under Astronomers Crommelin and Davidson for Sobral in northern Brazil, and the other, under Prof. Eddington and Mr. Cottingham, for Ile Principe in the Gulf of Guinea. At both stations the total phase of the eclipse was to last more than five minutes, and it was the plan of the observers to concentrate all their efforts on testing the new theories of light and the effect of gravitation upon the course of a ray of light.

The Bureau of Terrestrial Magnetism of the Carnegie Institute, under the directorship of

Dr. L. A. Bauer, made extensive plans for magnetic and other allied observations of this eclipse. Dr. Bauer left for England early in March, where he organized an expedition to be stationed either at Ile Principe or Libreville in the French Congo. From there he proceeded to South America to arrange for similar observations near Sobral, as well as at a number of stations outside the belt of totality. Various magnetic observatories, institutions and individuals offered their co-operation for this purpose.

Dr. C. G. Abbot, director of the astrophysical observatory of the Smithsonian Institution, left Washington the first of May for South America to observe the eclipse near Sobral, which was the chief station for observations on this continent. The eclipse was to occur in the early morning at this point, mid-totality coming shortly after 9 o'clock, while at Libreville, in the French Congo, totality was to occur shortly before 3 o'clock in the afternoon, local time.

The problem that the observers of this eclipse were anxious to solve is whether or not light obeys the laws of gravitation and is deflected from its course upon entering the field of the sun's attrac-

tion. Prof. Eddington, who was to observe the eclipse in the French Congo, characterized it as the problem of "weighing light."

According to the most recent theories light can no longer be regarded as an elastic wave motion of the universal ether that has been assumed to pervade all space, but rather as consisting of widely separated centres of energy whose particles vibrate singly.

It is known that light exerts pressure and has a finite velocity of 186,000 miles per second, and therefore it is reasonable to assume that it possesses mass, momentum and, in the vicinity of a strongly attractive body such as the sun, appreciable weight, provided it obeys the laws of gravitation. It was, therefore, to see if light is composed of material particles obeying the Newtonian law of gravitation that this eclipse was to be observed.

It is possible to determine just how far particles of matter coming from infinite space, in this instance rays of light from distant stars moving with a velocity of 186,000 miles per second, will be deflected from their course upon entering the field of the sun's attraction, just as one can trace the

path of a comet or meteor under the same conditions.

It can be shown that the path of any such particle will have the form of a hyperbola concave toward the sun and that the nearer the particles or light rays come to the sun's edge the greater will be the curvature of the paths and the greater the apparent displacement of the stars away from the sun. For a ray of star light just grazing the edge of the sun it has been found that a displacement of nearly one second of arc in the star's position is to be looked for if light obeys the law of gravitation. This would be the greatest displacement, for the nearer the rays pass to the sun the more strongly they are attracted and the more they are deflected from their course.

Obviously stars near the sun are invisible ordinarily. It is only during a total eclipse of the sun when the stars shine forth as on a moonlight night that it becomes possible to "weigh light" from observations of the stars in the vicinity of the sun.

During this eclipse, it was expected at least thirteen stars would be visible close to the sun's position. If displacements in the normal positions of all of these stars were observed and if the displace-

ments were greater the nearer the star came to the sun by the amount required by the theory it would be strong evidence in favor of the new theory that light possesses mass and weight and obeys the law of gravitation.

The uncertainties attending observations of such a nature are necessarily great. Aside from uncertainties as to weather conditions there is the possibility that the solar corona might affect the star positions, possibly refracting or blurring the images of the stars and thereby introducing errors in the measurements.

Errors of instruments must also be reduced to a minimum to make possible accurate measurements of these angles of displacement that, if existent, scarcely exceed the parallaxes of the nearest stars.

The expeditions fitted at the Royal Observatory of England expected to use the astrographic telescope employed for cataloguing the positions of the stars by photography, and it planned to make the exposures of the photographic plates of ten seconds duration. Comparisons of the positions of the thirteen stars obtained during the eclipse with the normal positions of these stars obtained when the sun is in another part of the heavens should

show the displacement due to the sun's influence on the path of a ray of light, if it exists.

It is also possible to test at the same time the noted Einstein theory of relativity that is the subject of so much discussion at the present time. According to this theory the velocity of light is less in a strong gravitational field than it is in a vacuum, and the displacement of the light from the stars that passed through the field of the sun's influence comes out twice that indicated by the first theory.

It was difficult to obtain any information bearing on these problems of light and gravitation during the United States eclipse of June 8, 1918, owing to the fact that the sun was at that time in a field of very few stars.

The results of the observations of this eclipse are not yet available but it is hoped that some of the expeditions were successful in obtaining photographs that will be of value in solving this unique problem of weighing light.

CHAPTER XX

ARE THERE OTHER PLANET WORLDS?

IF IT were possible for man to view the solar system from the distance of the nearest star, our glorious orb of day would appear as a first magnitude star, very similar to beautiful Capella, the star of yellow hue that shines so conspicuously near the meridian in northern skies in the early evening hours of February.

If our greatest telescopes could be turned upon the sun at this distance, the existence of his planet family would never be suspected. Jupiter, the greatest of the satellites, would be a star of the twenty-first magnitude, shining by reflected light only and situated but five seconds of arc distant from the sun. When we consider that the most powerful telescope in existence cannot show stars below the twenty-first magnitude, even under the

most favorable circumstances, the impossibility of detecting even the greatest of the sun's family at this distance is clearly evident.

The least distance that the unaided eye is able to distinguish between two stellar objects is more than 200 seconds of arc, so even if Jupiter shone with a lustre equal to that of the sun the two would appear as one star to the naked eye at the distance of the nearest star. As to the other planets: before the bounds of the solar system are passed, Mercury, Venus, Earth and Mars sink into invisibility, mere cosmic specks lost in the rays of a sun that is rapidly assuming a starlike appearance even at this distance.

We have likened the aspect of our sun at the distance of the nearest star, that is, at a distance of only four light years, to the brilliant Capella, and spoken of the total invisibility of its greatest satellite, the mighty Jupiter, at this distance. How would our glorious sun appear if it were situated at the same distance from us as this conspicuous star of winter skies forty light years away?

Instead of a brilliant first magnitude star we would barely see an insignificant point of light of the fifth magnitude, one-seventieth as bright as

Capella and near the limit of visibility for the unaided eye. And yet Capella is not very far away as star distances go in a sidereal universe some 300,000 light years in extent. Ten thousand light years away great telescopes could not pick up the tiny speck of light representing our sun among the innumerable hosts of the universe.

The inconceivably great distances separating the various suns that compose our universe render absolutely hopeless any attempt to investigate the planet families of other suns, if such exist, and we very reasonably suspect that other planet worlds do exist.

There are many stars in the stellar system that closely resemble our own. So the spectroscope tells us. Our sun is but one of the yellow stars. Line by line its spectrum is reproduced in many a star that is evidently composed of the same elements at practically the same stage of stellar evolution. If one member of this group is, to our knowledge, attended by a planet family, we can hardly assume that the reverse is true of all other stars of the same type. Inability to detect the presence of such worlds does not disprove their existence.

Possibly the day may come when some device at

present unknown, as the spectroscope was less than one hundred years ago, may accomplish as wonderful results in the detection of dark bodies in the universe, whether sun-like or planetary in size, as the spectroscope has in the detection of dark and light suns physically associated in double or multiple systems.

It is the spectroscope that tells us that beautiful Capella is not a single star, such as our own sun, but belongs to a star system composed of two bright stars, each approximately equal in mass to our own sun, that revolve around a common centre of gravity in about one hundred days and are separated from each other by a distance of about fifty million miles.

It is now well known that a large proportion of the stars are not single suns, but belong to systems of two, three or more suns in revolution around a common centre of gravity. The spectroscope tells us that some of these bodies are dark. They make known their presence only by the disturbance they produce in the motion of the bright stars with which they are associated. The fact that they can produce such disturbances proves that they are of sun-like dimensions and not planets. They are

dark either because they are extinct through old age or because they are, for some mysterious reason, imperfect radiators of light.

A satellite such as Jupiter that possesses only about one-thousandth of the mass of the sun it encircles could never appreciably affect the motion of its ruler. The spectroscope would not reveal the presence of such a modest attendant, though it possesses more than 300 times the mass and 1,300 times the volume of our planet Earth. Yet small planetary bodies may, for all we know, be members of double and multiple star systems. There may be all gradations in such systems from dark bodies of sun-like mass, capable of revealing their presence to observers hundreds or even thousands of light years distant, down to hopelessly obscure planets or planetoids such as our ringed Saturn, mighty Jupiter, modest planet Earth, or the numberless asteroids of the sun's family. The masses of celestial bodies can only be found through their attraction for other bodies. It is impossible to know anything definite about the masses of solitary stars since they lie so far apart.

Systems of connected stars, on the other hand, through the attraction of the various members for

each other, furnish a method for determining the combined masses of the stars in terms of our sun's mass when their distance from the earth is known. One of the interesting results of the investigations of the masses of these binary systems is to show that our sun is an average star. Though there are giants in the universe such as Arcturus or Canopus or Rigel that dwarf our sun into insignificance, and though nearly all the stars visible to the naked eye are far more brilliant than our luminary, they represent the exceptional stars. Among the telescopic stars, the countless hosts that go to form the sidereal universe, our sun is about the average in size and importance and in no respect remarkable unless we assume that, for some mysterious reason, the rays of this one alone are capable of fostering varied and multiple forms of life upon attendant planets.

Binary star systems often present strange and unexplained variations of light. In some instances light variations are due to the temporary eclipse of one member of the system by the other, as in the noted Algol system. There are, on the other hand, light changes in other binary stars not so easily explainable. The Cepheid variables, as they are

called, have so far defied all attempts at a satisfactory explanation of their peculiar behavior. They are characterized by a periodic variation of light of short duration. The entire cycle of change is usually accomplished in a few days, in some stars in a few hours. A very rapid rise to maximum brightness is followed by a prolonged drop to minimum that is sometimes interrupted by a weak attempt at an increase of brightness. This cycle of change is repeated continuously with clock-like precision.

Many explanations of the peculiar behavior of these stars have been suggested, though none fit all the requirements. According to one theory the peculiar light variations are due to internal oscillations of the stars resulting from collisions with planetary masses.

There are also the remarkable cluster variables found in some of the noted globular clusters composed of thousands of stars. They resemble the Cepheids in the nature of their light variations, though the periods are extremely short. The cycle of change is usually accomplished in less than twenty-four hours. Some stars wax while others wane, each star keeping strictly to its own period,

entirely independent of other stars in the same cluster.

This independence of each other is not so strange when we consider that the individual stars in the globular clusters are separated by distances comparable to the distance that separates our solar system from the nearest stars and that ample room is furnished each star for the possession of extensive satellite families without being crowded by too close stellar neighbors. Why some few stars in a globular cluster should show this unaccountable periodic flickering of light while the majority shine with clear and steady rays is another of the unexplained mysteries of this wonderful universe of which we form such a humble part.

CHAPTER XXI

DRIFT OF THE STAR STREAMS

THE sun, as is now well known, travels through the universe at the rate of twelve miles a second, or more than 1,000,000 miles a day. In a year it passes over four times the distance from the earth to the sun and after an interval of nearly 16,000 years has journeyed the same distance through space that light travels in one year.

The earth and other planets, of course, share this motion of their ruler, since the solar system moves as a unit with the relative motions and positions of its various members unaffected by the translation of the whole system through space. The revolution of the planets around the sun, combined with the motion of the system as a whole, causes their paths through space to assume the form of corkscrew spirals.

In the past five thousand years practically no changes appreciable to the naked eye have taken place in the forms of the constellations or the brightness of the stars due to this motion of the sun. After an interval of one hundred thousand years, however, which is less than the period man has been known to exist upon this planet, the individual motions of the stars combined with the sun's advance through the universe begins to noticeably alter the appearance of the constellations and the brightness of the nearer stars.

In this time the sun travels between six and seven light years, which is more than the distance that separates us from a few of the nearer stars. From the birth of a star to its extinction many journeys to and fro from one end to the other of the stellar system may be possible if the extent of the system of the stars to which we belong is limited in diameter.

In four hundred million years, a less time than has elapsed since the formation of the earth's surface crust, according to some geologists, the sun has journeyed so far through our stellar system that its light will take 25,000 years to retrace the path. In other words the sun has travelled in this

period 25,000 light years, which is sufficient to have brought it from far-distant star clouds of the Milky Way to its present position.

During this tremendous interval of time what portions of the heavens has our sun passed through? Has it moved in a straight line or in a closed orbit as do its own satellites?

How far, moreover, has it advanced in its evolution after pouring forth its rays of light and heat during this journey at a most extravagant rate with no sign of diminishing force? Unanswerable questions as yet. One fact is reasonably certain, however. No serious catastrophe, such as a collision with or close approach to a neighboring sun either dark or light, has occurred during this vast period. Wherever our sun has journeyed it has been allowed to trace its path undisturbed by outside influences.

The life process nas slowly and steadily advanced upon the earth and possibly upon other planets of the solar system as well during this period. As far as our own planet is concerned, evidence of this undisturbed development is stored away in geological formations.

Collisions or close approaches of stars are such

rare phenomena, occurring so far only in the more congested regions of the Milky Way, that it is stated as one of the fundamental laws of the universe that "the stars describe paths under the general attraction of the stellar system without interfering with one another."

One of the most interesting and important problems of modern astrophysics is to determine the form and extent of the system of stars to which we belong. A beginning at least has been made toward the solution of this problem. Material is being collected continually, day by day and year by year, bearing upon the number of the stars, their velocities both in the line of sight and across the line of sight, their distribution with reference to the plane of the Milky Way, which is recognized as the foundation of the system, and their physical characteristics as well, including relative masses, densities and luminosities.

One of the most important discoveries in astrophysics was made through painstaking examinations of the motions of a great number of stars. It was in 1904 that the noted astrophysicist Kapteyn first proved in this way the existence of two intermingling star streams and showed that

the motions of the stars were according to law and order and not at random.

More and more facts are gradually being gathered as to the nature of these two star streams. It has been established by this time that the great majority of the stars belong to one or the other of these two great streams. Also that the number of stars in the two streams are in the ratio of three to two and their velocities in the ratio of 1.52 to 0.86; that is, the stars in one stream are more numerous and move more rapidly than the stars of the other stream in the above proportions. It has been found, moreover, that the motion of one stream relative to the other is parallel to the plane of the Milky Way, emphasizing the importance of this formation in the stellar system.

It is a peculiar fact that the Orion or Helium stars scarcely partake of this star streaming tendency, though they show a decided inclination to drift in groups, all the members of a group moving in the same general direction and with the same speed.

The Pleiades and the chief stars in the constellation Orion are notable among these moving clusters. This gregarious habit is not entirely confined

to the Helium stars, for some stars as far advanced as the sun in evolution show the same trait.

The stars that most closely follow the directions of the two interpenetrating star streams are the Hydrogen stars. Their preference for these two streams is most marked. The older stars, especially the red stars, show a tendency to diverge from the directions of the two streams. The average rate of motion of the red stars of advanced age is three times as great as the extremely sluggish rate of the Orion stars and their independence of motion is much more marked, for they show no inclination to remain in or near the plane of the Milky Way, as do the earlier type stars.

Though the two star streams to which the majority of all the stars belong represent a fundamental feature of the stellar system, it is believed that they are but a first approximation to the motions of the stellar system. The more recent investigations in astrophysics, especially those connected with the spiral nebulæ and globular star clusters as external systems of stars, seem to indicate the possibility of a spiral form for the sidereal system to which we belong.

Nothing is known that contradicts this belief,

while the star streaming characteristic mentioned above is in line with the theory. It has been suggested by some astronomers that the dense star clouds of Cygnus or of Sagittarius may be the strongly condensed centre or nucleus of our stellar system and that the spiral arms lie along the plane of the Milky Way. Whether matter is flowing along the spiral arms toward the nucleus or from the nucleus outward along the spiral arms, streams of matter will flow in opposite directions where the arms merge into the central nucleus.

What would be the nature of stellar movements in a system possessing a double armed spiral formation cannot be stated until the dynamics of motion in spirals is known. At present there is no clue to the law that governs such motion.

If the stellar system is indeed a spiral formation, more extended study of the relative motions of the stars will eventually reveal the law that governs their motion. It might then be possible to trace the path of our sun through the system of the stars just as it is now possible to trace the paths followed by his satellites within the solar system.

CHAPTER XXII

THE MILKY WAY

TO THE people of all ages and nations the Milky Way or Galaxy has ever been an object of awe and admiration. Many beautiful though fanciful stories exist concerning it. It has been called both the Sky River and the Path of Souls. In Scandinavia, where it arches magnificently through the zenith in winter months, it is the Winter Street, and another favorite name for it is Jacob's Road.

The true immensity and grandeur of this girdle of the universe the human mind can hardly grasp. It is, as it were, the equatorial belt of the sidereal system and marks the outermost confines of the universe. The distances of the stars that belong to it must be measured by the thousands of light years.

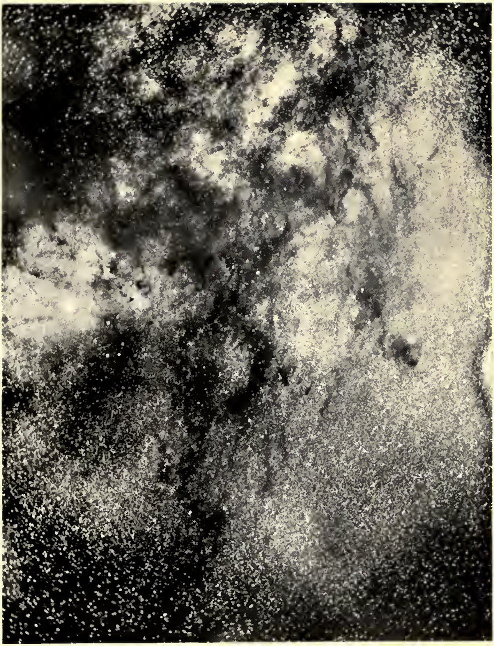
Suns heaped upon suns occur here in such pro-

fusion that in certain of the denser portions it is impossible to form any estimate of their true number. Nebulæ and star clusters as well as stars surrounded by nebulosity are intermingled with the dark lanes and stretches of inky blackness. An example of the latter is the Coal Sack in the Southern Cross, not visible in our latitudes. These darker portions are as characteristic of the Milky Way as the bright knots and streamers of light so frequently met with. Many of them are truly rifts in the star clouds through which we see into space beyond, but dark nebulous matter is also abundant in the Galaxy, in fact nebulosity both light and dark is a strong characteristic of galactic regions.

Here, too, tend to collect the younger members of the stellar system, the Wolf-Rayet or bright line stars, with a type of spectrum bordering upon that of gaseous nebulæ, and the helium stars. Both groups come early in stellar evolution. The Wolf-Rayet stars are never found anywhere except in the Milky Way and in the Greater and Lesser Magellanic Clouds, two small, somewhat circular regions in southern circumpolar skies very similar in nature to the Galaxy. The bluish-white helium

stars show a decided preference for the plane of the Milky Way and so also do the green or gaseous nebulæ and the temporary stars or Novæ. With hardly an exception the latter have flashed out in the regions of the Milky Way. On the other hand, the white or spiral nebulæ conspicuously avoid galactic regions and seek the neighborhood of the galactic poles, particularly in Virgo and Canes Venatici, in northern latitudes. It is believed by many astronomers that these spirals are not nebulæ at all but "island universes," as they are called, lying beyond our stellar universe and so distant that we cannot distinguish their true stellar nature. There is also the attendant theory that our own universe is of spiral form with its nucleus in some galactic region and its spiral arms in the plane of the Milky Way. If spiral nebulæ shall be found on future investigation to be, in truth, exterior universes it will be reasonable to assume by analogy that our universe also has a spiral form.

Counts of stars in various parts of the heavens have established the fact that the great majority of the stars in the universe crowd toward the galactic plane, and by far the greater number of



DARK MARKINGS IN THE MILKY WAY

(Photographed by Barnard on Mt. Wilson with the Bruce telescope)

these are actually within the bounds of the Milky Way. There is a noticeable thinning out of stars as we approach the galactic poles and an increase in the number of spiral nebulæ. This has led to the belief that the shape of our stellar universe is decidedly flattened in the direction of the galactic plane. It has been likened to a disk in shape, the most distant regions of the Milky Way marking the confines of our visible universe. It has been judged that our particular solar system at present occupies a position well within the Milky Way a little above the galactic plane and part way from its centre to its edge, far from the central aggregations of the Galaxy. This belief is based partly upon the form of the Milky Way as seen from our viewpoint. To us it appears as a great circle encompassing the heavens.

In northern latitudes the Milky Way is never seen to run due north and south or east and west, but crosses the sky diagonally and is best seen in fall or late summer. In spring it lies too near the horizon to be well observed. From circumpolar regions through Cassiopeia to Cepheus and into Cygnus it runs. Here it divides into two parallel branches for nearly one-third of its entire

length, running through Aquila, Ophiuchus and Sagittarius to Scorpio. There the two branches join once more and it passes beyond our vision into southern skies, where it enters Centaurus and Crux, the Southern Cross, and traverses the magnificent and extensive constellation of Argo Navis, which contains Canopus, the second brightest star in the heavens. From Argo Navis it curves northward once more, passing close by Canis Major, which contains Sirius, the brightest of the stars, and running through Monoceros, where it is extremely brilliant, to Gemini and Taurus, then through Auriga and Perseus to circumpolar regions in the neighborhood of Cassiopeia once more. Throughout this entire course it exhibits a wonderful diversity of form and structure. We note that it includes in its midst or passes near many of the brightest of the stars, while it includes an overwhelming majority of the fainter stars. The brilliancy of the Milky Way and its immediate neighborhood is in striking contrast to the dearth of stars near its poles.

Since the stellar system is undoubtedly condensed toward the plane of the Milky Way and we are situated between the centre and the edge of this

plane, it is evident that we look through a dense layer or stratum of stars in the direction of the Milky Way. All the stars that lie in the direction of the Galaxy do not belong in its midst, but are at varying distances from us. The true aggregations of the Galaxy are at excessive distances and are for this reason extremely faint, on the average between the fourteenth and sixteenth magnitude, and probably only in a few rare cases brighter than the eighth magnitude. As distinct points of light they are beyond the reach of the unaided eye and give us only the impression of hazy light.

Successful attempts have been made to portray various regions in the Milky Way, especially in Sagittarius and Cygnus, and we cannot fail to be impressed with the impossibility of making any estimate of the number of suns represented in some of these views. Such, moreover, is the diversity of form of its various parts that it has been said no one region can be regarded as typical of the entire Milky Way. The stupendous scale of this wonderful structure fills us with awe. Suns are here crowded together until they seem as countless as the grains of sand upon the seashore, and yet there is no doubt that they include among their

number some of the giants of the universe only dimmed to our eyes by immeasurable distances.

We cannot fail to recognize the fact that there is some definite plan or purpose in this structure in its relation to the remaining portions of our universe. It is not unmeaning chaos that we look upon, for certain types of stars crowd toward the Galaxy while others avoid it, and certain physical characteristics are shared by all of its members.

We can only stand awestruck before the plan of the universe that our minds cannot grasp or comprehend.

CHAPTER XXIII

DO DARK STARS EXIST IN THE HEAVENS?

DARK stars abound throughout the universe either in a solitary state or associated with brilliant companions. Though invisible, they have disclosed their presence to us in a variety of ways. It may never be possible to form any estimate of their true numbers, but we cannot doubt their existence.

Many a dark or feebly luminous body of sun-like dimensions has been detected by the perturbed motion of some bright star with which it is physically connected. Sirius and Procyon were observed to describe little ellipses under the influence of some unseen force long before their companions were discovered. The companion of Sirius, though not absolutely dark, is one of the most feebly luminous bodies known. Its mass, however, is nearly

one-half that of Sirius and it has a powerful attractive force.

It is now conservatively estimated that one star in every three is either double or multiple; that is, belongs to a system of two or more stars in revolution around a common centre of gravity, and in numberless cases dark stars are included in these systems. Sometimes the components of these systems are so close that in the most powerful telescopes they appear as a single star, but their composite nature is revealed by the spectroscope, which shows a doubling or shifting of the lines of the spectrum. These are called spectroscopic binary systems. The doubling of the spectral lines shows a second luminous body to be present, but the shifting of the lines without doubling shows that the bright star has a companion giving little or no light. As the bright body recedes in its orbit under the sway of its dark attendant the lines shift toward the red end of the spectrum, and as it turns in its orbit so as to approach the earth the lines shift toward the violet end of its spectrum, and the amount of the shift shows the velocity with which it moves in its orbit. In some cases it is possible to determine not only the time

it takes for the star to describe its orbit and the velocity with which it is moving, but also the distance between the two components in miles, their relative mass and brightness, and their mass and brightness as compared with that of our own sun. All this is possible, however, only in case the distance of the system from the solar system is known.

Stars are often variable in light due to periodical eclipse by dusky satellites. Such is Algol, the Demon Star, whose wink every three days means that a dark body passes before his face and shuts off fully five-sixths of his light. Stars that are regularly occulted or eclipsed by dark attendants form a large class of stars known as eclipsing variables. They furnish another proof of the existence of dark bodies.

It is of peculiar interest that dark stars are often associated with stars known to be young; that is, with Helium or Sirian stars. Since members of double star systems have presumably at one time formed a single mass, gradually separating into two or more components and drawing further and further apart as time goes on, we would expect the components to show signs of equal age. Why should they be in so many cases

of nearly equal mass, but widely different light giving power? We must conclude that there are two classes of dark stars, those dark through old age coming at the end of the evolutionary stage, and those dark because they are imperfect radiators and have not the necessary physical properties for keeping up long continued radiation without appreciable loss of light and heat. Possibly at the time of their separation from the original mass there was unequal distribution of the materials possessing the light and heat giving properties needed for long continued radiation. We can only conjecture as to the cause, but the fact remains that intensely brilliant stars with every sign of youth are physically connected with stars necessarily of equal age but emitting no appreciable light. Such well known bright stars as Sirius, Spica, Procyon and Castor are attended by faint or invisible companions.

Whether there exist in space systems in which all the members are dark we have no means of knowing, but we can reasonably assume that as old age overtakes the brighter members of these systems they too will become dark. The systems of 61 Cygni, one of our nearer neighbors, includes one

or more invisible members, and the entire system shows signs of great age. There seems no escape from the conclusion that in far distant ages the entire system will be devoid of light. Investigations are also establishing the fact that the velocity through space of stars and star systems increases with age. If so, with what tremendous velocity extinct stars must be rushing on their mysterious journeys to unknown fates!

We have been considering so far dark stars that are associated with bright companions. The sudden blazing forth of temporary stars has led to the belief that dark stars occur in an isolated state as well. It is only when collisions between dark stars occur or when dark bodies pass through resisting nebulous matter with the attendant bursting forth of light that we can know of their existence.

Our own sun in his old age would be a star of this class. For the ruler of our solar system is supreme and shares his glory with no other body of sunlike dimensions. Our own system may be but one of many that have dark attendant satellites vastly inferior in mass to the ruling body around which they circulate. And when old age falls upon

the ruler of such a system and his light and heat have disappeared he has no choice but to join the host of dark stars, as cold and inert as his lifeless attendants that still circle ceaselessly around their ruler as he journeys onward to extinction. We can only reason about the existence of such dark and lifeless systems through analogy. We see in the heavens the nebulæ that give birth to stars. We see also young stars, and stars in the zenith of their splendor, such as our own sun, and again stars failing in light and heat with advancing old age; and why not cold, rayless stars?

It is known that stars exist in a non-luminous condition in mixed systems of light and dark stars. The telescope and spectroscope prove this to us. So it is reasonable to assume that dark bodies exist among the single stars.

Dark bodies of planetary size attendant upon bright stars could never be detected by any means at our disposal, for bodies shining only by reflected light from a central sun and of such minute proportions compared with their luminary would be hopelessly lost in his rays. It is only when a satellite has sunlike dimensions that it can influ-

ence the ruler of the system and reveal its presence by the perturbations it produces. If our most powerful telescopes were placed at the distance of Alpha Centauri, the nearest star, and pointed at our solar system, it would never disclose the fact that our sun had a single attendant planet.

It is doubtful if we can ever fulfil our very natural desire to know whether other stars are attended by worlds of planetary size.

As regards dark suns, however, Bessel, one of the greatest of mathematicians, said we had reason to believe there may be as many dark stars as bright ones.

CHAPTER XXIV

THE BRILLIANT NOVA OF 1918, NOVA AQUILÆ NO. 3

SHORTLY after the moon's shadow had swept across the United States on the 8th of June, 1918, and while, in fact, members of many successful eclipse expeditions were busily engaged in developing plates and packing up eclipse apparatus, there suddenly appeared in the heavens, in the constellation Aquila, the Eagle, the most brilliant temporary star or nova that has been seen since Kepler's star suddenly flashed into view in 1604, more than three hundred years ago.

According to a Harvard College Observatory bulletin numerous telegrams were received at the Harvard Observatory during the night of June 8 from all parts of the United States and Europe announcing the independent discovery of the nova by many amateur and professional astronomers.

The first person to report the discovery was Mr. W. H. Cudworth, who sent a telephone message from Norwood, Mass. Due to differences in longitude the star was probably first seen in Europe. Harvard observers immediately proceeded to photograph the visitor and look up its past history.

Photographic plates dating back as far as May 22, 1888, showed a faint star of the eleventh magnitude whose position in the heavens was identical with that of the nova. Several hundred plates were examined at the Harvard Observatory in order to trace the light variations of this star in the past thirty years. There appear to have been slight fluctuations in the brightness of the star during that period that have a range of about half a magnitude.

The following facts were established from examination of photographs. On June 3 this wonderful star possessed its normal brightness for the past thirty years, that of a faint star of the eleventh magnitude. Because of clouds no plates were exposed on June 4, 5 and 6. On June 7 the star appeared as a sixth magnitude star just at the limit of visibility to the unaided eye. Its brightness had therefore increased one hundred fold in

less than four days. On June 8, the memorable day of its discovery, it had become a star of the 0.5 magnitude and was a magnificent blue-white star nearly as bright as Vega, shining all the more resplendently since it appeared in a part of the heavens where few first magnitude stars appear.

Upon June 9 Nova Aquilæ No. 3, as it has been labelled astronomically, attained what appears now to have been its maximum brightness, when it outshone the famous Nova Persei of 1901 and practically equalled Sirius in brilliancy. According to observations of Prof. E. E. Barnard, made June 9, its magnitude was minus 1.4, while the magnitude of Sirius is given as minus 1.6.

How long it will remain visible to the naked eye is doubtful. Nova Persei faded from view within a month and was conspicuous for only a few days. It was unlike the present nova in being distinctly ruddy at maximum brightness. It is customary for temporary stars to fade rapidly but fitfully away. Kepler's star, which was nearly as bright as Venus at maximum brightness, was unusual among temporary stars in remaining visible for fully two years.

The nova is situated in one of the two branches

of the Milky Way, that lie between Aquila and Scorpio, and it was all the more conspicuous for appearing in a portion of the heavens where few bright stars are seen.

On June 8 the spectrum of the nova was found to be that of an early type star, with dark lines due to absorption of the light of the stellar core by cooler hydrogen gas surrounding the star. A spectrum taken at Harvard on June 9 confirmed the first observation and showed narrow, dark hydrogen lines on a nearly continuous background.

All astronomers agree that the sudden outburst of novæ, a rare phenomenon, is evidence of some sort of a celestial catastrophe, but the exact cause of the sudden and tremendous increase in the light giving powers of the star is still in doubt. The latest theory assumes that a dark or light star encounters a stream of nebulous matter, and its heat and light are enormously increased by the friction created by its passage through the nebula. Considerable weight is given to this theory by the fact that Nova Persei was observed to be surrounded by nebulous matter soon after its sudden appearance. Nebular conditions still exist around this star, which is still visible in large telescopes.

At first it was thought that matter was travelling outward from the star with the velocity of thousands of miles per second, but this appeared most unlikely, and it was finally shown that the phenomenon could be explained by assuming that the surrounding nebula was illuminated by the waves of light proceeding outward from the star. Light was being reflected to us from the dark nebula just as the planets and moon reflect the light of the sun. The theory of the origin of novæ by encounters between stars and nebulous matter does not satisfactorily explain all that has been observed in connection with the appearance of these stars, and the origin of novæ is still a subject open to discussion.

The novæ show no measurable parallax and therefore their distance is unknown, but it is assumed to be very great, certainly not less than 300 light years, possibly in some instances, several thousand light years.

The great value of preserving photographic records of the heavens appears in connection with the discovery of this star. It is possible to prove by reference to the photographs of this portion of the sky taken at the Harvard College Observa-

tory that the present nova was not a dark star previous to its present outburst, but a faint star of the eleventh magnitude, and all its past history for thirty years is now available. The sudden rise of this star to the minus one and four-tenths magnitude represents an increase in light giving power of about ninety thousand fold. In other words, when this star attained its greatest brilliancy on June 9 it would have taken the combined light of 90,000 stars of its former brightness to equal it.

Since Nova Aquilæ has no measurable parallax it must have been before its outburst at least equal in brightness to our own sun. At the time of its outburst its light was therefore equal to the light of many thousand such suns as our own. It is possible that Nova Aquilæ is situated in distant regions of the Milky Way where lie vast nebulous tracts of matter, and that even before its outburst it was superior to our own sun in brilliancy.

Possibly at the time of its outburst a catastrophe became visible that took place several thousand years ago, for if the star is several thousand light years distant the light that now reaches us started on its journey many centuries ago.

Since the date of its discovery astronomers have

obtained many spectroscopic records of the changes that have taken place in this brilliant nova. Following the usual course of temporary stars Nova Aquilæ No. 3 decreased fitfully but rapidly in brightness and in a few months became a faint fifth magnitude star, just perceptible to the naked eye.

CHAPTER XXV

CALCIUM GAS IN THE MILKY WAY

NOVA AQUILÆ No. 3, the brilliant temporary star that suddenly burst forth June 8, 1918, and then rapidly decreased in brightness until it is now scarcely visible to the eye, has been under continual observation by astronomers since the date of its first appearance.

A most unusual and unexpected result of the spectroscopic study of this star has been the detection of clouds of calcium vapor lying in the Milky Way between us and the new star.

This discovery has been announced in a communication to the *Observatory,* a British publication, by the prominent British astronomer Evershed, stationed at Hodaikanal, India, who reports the existence of fine dark lines of calcium in the spectrum of the nova in a normal position. Since

all the spectral lines of a nova are always greatly displaced and distorted, due to the abnormal conditions existing in such stars, the presence of the lines of any element in a normal position points to an origin of these lines external to the scene of the outburst.

According to one of the first laws of spectrum analysis, upon which depends our knowledge of the physical condition of the stars, if light from a certain source, such as an incandescent solid, or liquid, or gas, under extremely high pressure (in this case the nova), passes through a cooler intervening gas, the latter will absorb from the source of light beyond the particular elements of which the cooler gas consists and as a result the spectrum of the hotter body (the nova) will be crossed by dark absorption lines of the cooler intervening gas.

It is upon this same principle that the elements that enter into the composition of the cooler enveloping gases of a stellar body can be determined. Upon the continuous band of color emanating from the star's interior appear the dark absorption lines originating in the cooler atmosphere of the star.

Were the outer gaseous envelope of Nova Aquilæ in a normal condition of temperature and pressure its absorption lines would be in their normal position in the spectrum, and the existence of these clouds of calcium vapor lying in the Milky Way between us and the nova would not have been suspected, since in that case the lines of calcium in the star's atmosphere and in the exterior clouds of calcium would have been coincident and would have been attributed entirely to a stellar origin. In the atmosphere of a nova, however, conditions are far from normal.

A celestial catastrophe has occurred and abnormal conditions of temperature and pressure existing in the star's outer gaseous envelope are registered in the form of distorted and displaced lines and bands both bright and dark in the star's spectrum. Only the lines of calcium vapor far exterior to the scene of the catastrophe remain uninfluenced by these conditions and appear fine and dark with the distorted, abnormal spectrum of the nova for a background. Remove the nova, or place in its stead a normal star, and the presence of the calcium clouds would remain unknown.

Continuing his investigation of the calcium lines

in Nova Aquilæ and looking up the records of past novæ and a number of binary stars, which also show displaced lines due to the mutual revolution of the components of each system, Evershed made some additional discoveries of great interest. Observations had been recorded in the past of the existence of the dark absorption lines of calcium in the spectrum of Nova Persei, which appeared in 1901 and closely rivalled Nova Aquilæ in splendor.

The lines of calcium also appeared in their normal position in this nova, though all the other lines of its spectrum were displaced. A few binary stars also showed the calcium lines in a normal position, though all lines originating in the atmosphere of these stars were displaced owing to mutual revolution of the components of these star systems which produces periodic displacements of all their spectral lines. Evershed concluded as a result of his observations of all these stars, ten or twelve in number scattered over widely separated regions, that there exists in the Milky Way vast clouds of calcium vapor through which the light of these stars passes before it reaches our eyes, and he also concluded as a result of further

investigations that these clouds lie virtually stationary in space. So immovable do they appear that he considers they would furnish a valuable method for a new determination of the motion of our own sun through space.

It has long been known that vast clouds of nebulous matter exist in the Milky Way, but this is the first time that the presence of a gaseous tract of matter has been detected by absorption lines produced in the spectrum of a star far exterior. It is a most unique and unusual discovery, and shows what valuable and unexpected results may be obtained from spectroscopic observations of the stars. Under ordinary circumstances, the existence of these vast clouds of calcium vapor would be unknown and unsuspected.

A normal stellar spectrum would not reveal their presence. Yet the rays of light from Nova Aquilæ and Nova Persei, as well as certain binary star systems, have not only told the secret of the physical condition of these stars but have also brought us the proof of encounters with intervening gases on their long journey through space to the solar system and our own planet.

An interesting and valuable field for future

study has thus been indicated. Observations of other stars with displaced spectral lines may enable astronomers to detect the presence of clouds of gas lying between us and such stars and to determine in addition whether these clouds of vapor are at rest or drifting through space.

Why calcium vapor should exist in such profusion in space is a mystery. As is well known to astronomers, there is a certain type of stars known as calcium stars, whose spectra are characterized by the presence of strong absorption lines of calcium, indicating that calcium vapor occurs in great abundance in the atmosphere of such stars. To this class of stars belongs Canopus, one of the greatest suns of the universe, and Procyon, a near neighbor of the solar system, which is about ten times more luminous than the sun.

In addition to dominating the spectra of stars of this class calcium is found in great quantities in the solar type stars, to which our own sun belongs, and less conspicuously in later type stars. It is only in the helium and hydrogen stars that this element appears to be absent. The distribution of this element in the atmosphere of the sun can be studied by means of the spectro-heliograph,

which makes it possible to photograph the sun in the light of a single spectral line.

The circulation of calcium vapor in the sun's atmosphere has been extensively studied by this method, and it has been noted as a singular and puzzling fact by astronomers interested in solar research that the vapors of this comparatively heavy element are frequently found at very high levels in the sun's atmosphere.

It is, moreover, a noteworthy fact that this element, which apparently occurs in the greatest abundance in stars of many types, and, as is now known, exists in different portions of the universe in the form of vast clouds, is also of the greatest importance upon our own planet, earth.

It is this element that enters into the structure of the bones and is so essential to virtually all forms of animal life. Though its particular importance in the fashioning of the stars and in the universe as a whole is unknown, it is certain that without it animal life as it now exists on our planet would be impossible.

CHAPTER XXVI

THE SPIRAL NEBULÆ AND THE GREAT NEBULA IN ANDROMEDA

THE discovery in recent years of a number of novæ, or temporary stars, in spiral nebulæ is regarded by astronomers as a matter of unusual importance since it may have a direct bearing upon the baffling problem of the nature, size and distance of these peculiar spiral formations now known to exist in the heavens in numbers running into the hundreds of thousands, if not millions.

It would in no wise lessen our interest in the most famous of all spirals, the Great Andromeda Nebula, to discover that it is an "island universe" consisting of millions of suns as well as vast nebulous formations and star clusters similar to those found in the Milky Way of our own system.

According to astronomers who have made a spe-

cial study of these spiral formations, dimensions and distances of a higher order than that of the stars are to be expected for the spiral nebulæ if they are remote universes

The marked distribution of all stars, star clusters and gaseous nebulæ within our own universe with reference to the Milky Way, or Galaxy, has long been known. In or near this plane are to be found the majority of all stars, bright as well as faint—though the condensation is more marked for faint stars—showing that our system is decidedly flattened toward the plane of the Galaxy. The tendency of the gaseous nebulæ and the planetary nebulæ, as well as the vast star clouds and tracts of irregular nebulous formations, dark as well as light, to adhere closely to the neighborhood of the Galaxy is well known.

In marked contrast to this we find that the spiral nebulæ actually avoid the regions of the Milky Way and are found in greatest abundance in parts of the heavens farthest removed from galactic regions; and, what is of special interest in this connection, all temporary stars discovered up to the present time, about thirty in number, have been closely confined to the Milky Way, with but three

exceptions. One of these, T Coronæ, was not a typical nova. The other two were found in spiral nebulæ and were the only temporary stars known to exist in spirals until quite recently, when Prof. Ritchey at Mount Wilson discovered a nova in the spiral nebula N. G. C. 6946.

The discovery of this nova, the third to be found in a spiral, caused a suspicion that there might be an actual physical connection between the spiral formation and the star. The probability that three temporary stars should chance to be in line with spiral nebulæ was very small. The discovery of this nova led to a reëxamination of former photographs of spiral nebulæ with the result that eleven temporary stars were found in spiral nebulæ as against twenty-six previously found in the Milky Way. Throughout the remainder of the heavens temporary stars are nonexistent.

Another extremely important point brought out by astronomers in connection with the discovery of these temporary stars in spirals is the great difference in the brightness of the novæ in spirals and the novæ in the Milky Way. Temporary stars that have appeared in the Milky Way have usually

THE GREAT SPIRAL NEBULA IN ANDROMEDA

(Photographed by Ritchey with the 2-ft. reflector of the Yerkes Observatory)

been somewhat sensational objects, in some cases appearing at their maximum fully as brilliant as the brightest of the stars or even the planets Jupiter or Venus. The novæ in spiral nebulæ, on the contrary, are excessively faint objects, averaging about the fifteenth magnitude, entirely invisible at their maximum brightness except in the most powerful telescopes.

Between the average brightness of the temporary stars appearing in the Milky Way and those detected in spirals there is a difference of fully ten magnitudes. If we assume that the two classes of novæ are about the same in actual luminosity this great difference in apparent brightness is due to differences in distance. A difference of ten magnitudes in apparent brightness of two stars that are in reality of equal light giving power means that the fainter star is one hundred times more distant than the brighter. We have no knowledge of the actual distance from us of the temporary stars situated in or near the Milky Way, but it is believed to be very great, probably in many cases as high as several thousand light years. This would place the spirals at distances to be measured by hundreds of thousands of light years and give

support to the theory that they are "island universes" of millions of suns.

Even with the sixty-inch reflector of the Mount Wilson Observatory no star in the heavens fainter than the twentieth magnitude can be detected. Photographs of spirals taken with this instrument show no individual stars, but nebulous, starlike condensations analogous probably to the nebulous star clouds of our own Galaxy, its star clusters and its nebulous formations. The appearance of a temporary star of the fifteenth magnitude in a spiral nebula would therefore mean the appearance of a star that is at least several hundred times brighter than the brightest individual star in the nebula, while the nova of 1885 in the Great Andromeda Nebula, which was of the seventh magnitude at maximum and therefore almost visible to the naked eye, must have attained an actual luminosity hardly to be equaled by the combined light of a million of the brightest stars in the heavens.

Dr. Shapley has pointed out that this unusual case would have a parallel in our own Galaxy, however, if we make the assumption that Nova Persei, the famous temporary star of 1901, is situ-

ated in some one of our most distant galactic clouds. The noted temporary stars of Hipparchus and Tycho Brahe may have originated in far distant galactic regions for all we know to the contrary. If so they burst forth with a temporary splendor equal to several million such suns as our own.

Though the question of the true nature of spiral nebulæ is still an open one, the appearance of extremely faint novæ in their midst must be conceded to be a strong argument in favor of the view that they are far distant external universes of the order of magnitude of our own stellar system and of the attendant theory that our own universe, composed of some hundreds of millions of stars and nebulous formations, luminous as well as non-luminous, has a spiral formation with the double branching spiral arms to be traced among the star clouds of the Galaxy. Upon the assumption that the spirals are far distant universes, the fact that they so conspicuously avoid galactic regions in strong contradistinction to nearly all other classes of objects in the heavens is explainable. If they are situated at distances more remote than other celestial objects the vast tracts of nebulous matter, dark and light, in galactic regions and the dense

star clouds that abound in this plane would hide from view spirals lying near the Milky Way.

Were our own system of stars as far away as the Great Nebula in Andromeda it would appear very much as the Great Nebula in Andromeda does to us. Without telescopic aid it would be seen as a faint patch of light about the size of the full moon. When viewed with the most powerful telescopes its most brilliant individual stars would still remain hopelessly invisible, but various nebulous condensations of light would appear, suggesting conglomerations of many stars and nebulæ. Our own little sun at this distance would be beyond the range of all telescopes. There would be little reason to suspect we were viewing a universe of hundreds of millions of suns or that all these suns were in unceasing motion in obedience to the mysterious laws governing their formation and that of the universe to which they belong.

Since the Andromeda Nebula is exceptionally large, it is either comparatively near or an unusually large formation. Many of the spiral nebulæ are extremely faint. They appear in the greatest abundance in the heavens. Of the fainter nebulæ virtually nothing is known. The thought that these

faint spirals may be aggregations of suns at distances to be measured by hundreds of thousands of light years is staggering to the imagination of man.

CHAPTER XXVII

GASEOUS NEBULÆ AND THE ORIGIN OF THE STARS

THE gaseous or green nebulæ, so named from the greenish tinge imparted to them by the presence of the unknown gas nebulium, present problems to the astronomer as interesting and important as those connected with the noted spiral nebulæ. These two types of nebulæ are radically different in their composition and in their distribution in the heavens.

Gaseous nebulæ are beyond a doubt members of our own system of stars. They crowd densely toward the Milky Way, the groundwork of our universe. The spirals as conspicuously avoid it. The latter, it is suspected, may be systems of stars independent of and external to our own. The gaseous nebulæ we think of as the material from which the stars are fashioned.

Their extent is enormous. We have as yet no definite idea of their distance, but it must be as great as that of the nearer stars. Most probably they occur in greatest profusion among the more dense star clouds of the Milky Way at distances to be measured by thousands of light years. In many cases they must occupy an interval of space so great that light would require many years to cross it.

Vast gaseous nebulæ enwrap, in some instances, moving clusters composed of many stars such as the Pleiades and the stars of Orion. The Great Orion nebula is the finest of all the gaseous nebulæ. Double, triple and multiple stars are enmeshed in its extensive folds.

The extreme tenuity of the gaseous nebulæ is as astonishing as their vast extent. One ten thousand millionth of the density of our own atmosphere at standard pressure is one of the estimates of the density of the denser portions of the Great Nebula in Orion.

It is difficult to imagine the condition of matter in such an extreme state of rarefaction. Yet these nebulæ assume an infinite variety of form and structure. In addition to the vast nebulæ of

irregular form there are the ring or annular nebulæ, peculiar formations probably spheroidal in form, with a star of variable luster often shining within the ring. There are the Saturn nebula, the Owl, Crab, Dumb-bell, North America and many other odd shaped gaseous nebulæ frequently named from their fancied resemblance to objects familiar to terrestrial inhabitants.

There are also the planetary nebulæ, a species of gaseous nebulæ named from their resemblance to faint planetary disks, that are receiving considerable attention at the present time. Astronomers find their extremely high velocities of motion in the line of sight which average twenty-four miles a second surprising and extremely puzzling.

In the scheme of stellar evolution the first type stars, on the border between nebulous and stellar conditions, are supposed to follow the planetary nebulæ in order of development, but the very high velocity of the planetary nebulæ would hardly connect them with the slowly moving new stars. It has been found that the stars move more rapidly with increasing age and we should therefore have to place the planetary nebulæ at the end of the evolutionary chain instead of the beginning, if we

consider simply the very high speed with which they are moving through space.

Some recent investigations of these same planetary nebulæ show that they are rotating as well and that in two special cases the periods of rotation lie between 600 and 14,000 years and the masses of the rotating nebulæ between three and 100 times that of the sun.

The planetary nebulæ are usually strongly condensed toward their centres. Here are found the denser helium and nebulium gases, while hydrogen occurs chiefly near the outlying portions.

These three gases, hydrogen, helium and nebulium, are the elements always to be found in the gaseous nebulæ, whether irregular or planetary. They enter into the composition of all nebulæ except the spirals, which shine on the other hand with "white" light and give the continuous spectrum of incandescent solids or liquids or gases under high pressure. They are for this reason often referred to as the white nebulæ, as opposed to the green or gaseous nebulæ. The latter show the typical nebular spectrum consisting of bright lines of the three gases mentioned.

A bright line spectrum indicates that the source

of the illumination is gaseous matter at low pressure. The green nebulæ are very feebly luminous and the nature of their luminosity is one of their most puzzling features. According to a recent theory the mysterious element nebulium is some familiar element electrically excited. Some astronomers believe that the luminosity of the gaseous nebulæ is chiefly due to electrical excitement of certain portions. In all these nebulæ occur dark portions as well as light. The illumination is locally condensed and certain portions seem for some inexplicable reason to have lost their illuminative power. This would hardly be expected if the luminosity of the gaseous nebulæ were due to light of incandescence alone. A more uniform distribution of light would be expected. It is generally believed that the temperature of the gaseous nebulæ is extremely low and if due to electrical discharges their average temperature might approximate to absolute zero.

Tremendous extent, extremely low density and marked feebleness of light are the three peculiar characteristics of the gaseous nebulæ.

Evidently plan and purpose control the nebulæ as well as the stars. They do not represent mean-

ingless chaos, but form one of the links in the chain of evolution.

It is not by chance that stars, both single and multiple, are found in the midst of the vast irregular nebulæ, while even the small planetary nebulæ, the annular nebulæ and the nondescript nebulæ have in nearly all instances stars closely associated with them.

It has been pointed out by some astronomers who are inclined to question the transformation from nebulæ to stars that the nebulosity connected with these stars may rather result from gradual change of stars into nebulæ, and that the nebulosity surrounding the Pleiades and the stars of Orion are rather emanations of gaseous matter from these stars and that eventually they will all be dissipated into nebular form. It has been pointed out also in this connection that flames of hydrogen and helium often burst forth from the solar surface at the rate of 200 miles per second even under present conditions, while a velocity of ejection of 380 miles per second would permit them to leave the surface of the sun never to return.

The nebulous matter now to be found surround-

ing the famous temporary star, Nova Persei, is instanced in support of the view that stars may be dissipated gradually or suddenly into a nebulous state.

Although the existence of dark nebulæ closely resembling the luminous variety in form seems to show that some nebulæ at least may become extinct without passing through the usually accepted order of evolution from nebulæ to star, the theory that gaseous nebulæ do not condense into stars would leave the question of the origin of stars entirely unsettled. That there is a continual cycle of change from nebulæ to star and possibly also from star back to nebulæ by chance encounter of one star with another or close approach of two stars seems more in accord with observed conditions. The passage of a star through a stream of dark nebulous matter would doubtless result in such nebular conditions as are observed in the case of the temporary stars, Nova Persei, Nova Aquilæ and others.

Man is handicapped in his observations of the nebulæ by the fact that changes in the form and structure of these objects are so extremely slow. A hundred or a thousand years is but a moment in

the life of a nebula. It is, therefore, next to impossible to detect a progressive change in any one nebula that would show whether condensation or expansion is taking place.

The spectroscope has furnished much valuable information concerning the gaseous nebulæ. In fact, practically all we know about these objects has been obtained with the aid of the spectroscope. We trust also that it will eventually solve the mystery of the strange gas nebulium that is the most characteristic element of the gaseous nebulæ. The fact that it is unknown elsewhere but adds to the mystery. The condensation of the gaseous nebulæ into stars and the final transformation of stars back to nebulæ through chance encounters and collisions pictures a state of universal and continual change, a universe without beginning or end, and in absence of proof to the contrary this is generally believed to be the true cycle of change that is taking place among the stars.

CHAPTER XXVIII

THE GREAT STAR CLUSTER IN HERCULES

AN extensive study of the great star cluster in Hercules, in connection with other globular star clusters, has been made at the Mount Wilson observatory and results seem to indicate that the parallax of this noted cluster is less thain one-ten-thousandth of a second of arc, and that it is at a distance of 37,000 light years, with a diameter of several hundred light years.

This faint wisp of light, barely visible to the unaided eye on clear, dark, summer nights, thus takes on the dimensions of a sidereal universe separated from us by immensities of space so vast that our minds utterly fail to grasp them. Thirty-seven thousand years ago then, if the above estimates are correct, the light that now comes to us from this gorgeous assemblage of suns started forth

on its journey at the rate of 186,000 miles a second, and if the cluster were suddenly blotted out of existence another 37,000 years would elapse before our solar system would fail to receive its light.

Only the most powerful telescopes are capable of completely resolving the Hercules cluster into its stellar components. Of more than 5,000 stars counted upon one photograph fully 4,000 were fainter than the thirteen and one-half magnitude and, therefore, invisible as separate stars in small telescopes. Long photographic exposures made with the largest reflecting telescopes bring out great numbers of extremely faint stars in this cluster lying near the limit of visibility of these great instruments.

When we consider that the entire space covered by the Hercules cluster is only about one-sixteenth of the area of the full moon, it seems almost inconceivable that this insignificant little patch of light represents a mighty assemblage of suns.

A peculiar distribution of stars has been noted in the Hercules cluster. The brighter stars extend outward from the centre in curved lines, while the extremely faint stars show a uniformly globular

distribution. Three dark lanes making an equiangular juncture near the centre of the cluster were detected many years ago and later photographs show a similar formation repeated at other points, which implies the existence of some definite law of formation.

The Hercules cluster is considered the finest globular cluster in the northern heavens, though it is surpassed in splendor by two clusters in the southern hemisphere in the constellations Centaurus and Tucana. Over 6,000 stars have been counted in the Centaurus cluster within a space about as large as that filled by the full moon, and they average about twelve and one-half magnitude, a magnitude brighter than those in the Hercules cluster. In this cluster, also, many extremely faint stars are present. The globular cluster in Tucana is somewhat smaller than the Centaurus cluster and contains about 2,000 bright members that are, however, more closely crowded together than are the members of the cluster in Centaurus. The globular cluster in Tucana, which is a constellation near the South Pole, is regarded by some as the finest object in the heavens. The dark lanes noticeable in the Hercules cluster are entirely absent in the

two southern clusters, which show a decided central crowding of the brighter stars as well as of the extremely faint members.

The distance of the Lesser Magellanic Cloud, which appears very much like a star cloud detached from the Milky Way, but which lies too far from the plane of the galaxy to be considered a portion of this girdle of the heavens, has been estimated at 30,000 light years. The Milky Way, which defines the outer limits of our own sidereal system, is generally believed to consist of several branches lying one beyond the other. The nearer portions, it is estimated, lie somewhere between 3,000 and 15,000 light years distant. Estimates of the distance vary, according to whether or not we include stars as bright as the sixth magnitude among the hosts of stars that crowd these regions. The vast majority of stars that form the star dust of the galaxy range from the fourteenth to the sixteenth magnitude. It is interesting to consider in this connection that a star 10,000 times as luminous as the sun would appear as a ninth magnitude star at a distance of 20,000 light years. If we admit the presence of stars brighter than the ninth magnitude in the nearer portions of the Milky

Way we must either admit the presence of veritable giants in our sidereal system, stars that are even more than 10,000 times as great as our own sun in brilliancy, or we must limit the extent of our stellar system and assume that the nearer star clouds in the galaxy are but 2,000 or 3,000 light years distant.

A class of objects far more numerous than the globular star clusters that lie at immeasurable distances are the spiral nebulæ, often spoken of as the white nebulæ, to distinguish them from the green or gaseous nebulæ. The idea that these are external sidereal systems or "island universes" has recently been revived. Many years ago, before the day of large telescopes and of the spectroscope, it was believed that all nebulæ were star clusters that could be resolved into separate stars by telescopes of sufficient power, but when the larger telescopes were obtained it was found that they could not resolve some of the nebulæ into star clusters, and finally along came the spectroscope to prove the truly gaseous nature of the green nebulæ. As to the nature of the spiral nebulæ, however, we are still in doubt. The spectroscope simply tells us that they have a type of spectrum known as "con-

tinuous,'' which may belong to a solid or liquid substance at high temperature or to an incandescent gas under high pressure. In this case the spectroscope refuses to give us any information.

We are familiar with the idea that our solar system is evolved from a nebula, but the spiral nebulæ to which we refer are far too vast to give birth to anything as simple as a single sun and its satellites or even to arise, on the other hand, from the close approach of two stars. Nothing less than clusters of suns could be evolved from nebulæ as extensive as these. The evolution of groups of stars from irregular gaseous nebulæ, such as the Orion nebula and the nebula surrounding the Pleiades, is a process now going on before our eyes. There are also moving clusters of stars, such as the Taurus cluster, which is known to include thirty-nine stars far exceeding our own sun in size and splendor, that may have evolved from one nebula. The latter star cluster has been very extensively studied and it has been estimated that in something like 65,000,000 years it will appear as an ordinary globular star cluster about twenty minutes in diameter, or two-thirds the diameter of the

full moon, if it keeps up its present rate and direction of motion.

If future investigations of spiral nebulæ shall disclose the fact that these formations that occur in such great numbers are indeed far beyond the limits of our own universe and form isolated stellar systems, as now appears to be the case with the Hercules star cluster, light may be thrown upon some perplexing questions that arise concerning the form and extent of our own sidereal system. According to some astronomers a spiral form for our own stellar system fits in better than any other with all the known facts concerning it.

CHAPTER XXIX

WONDERS OF THE GLOBULAR STAR CLUSTERS

INVESTIGATIONS made in the past few years by Dr. Harlow Shapley at the Mount Wilson Solar Observatory in regard to the distances and distribution of about seventy globular star clusters have brought results amazing even to the astronomers themselves, accustomed though they are to dealing with inconceivably great intervals of space and time, and have greatly broadened our ideas of the form and extent of the visible universe.

The following facts respecting these wonderful star systems have been gleaned from several extremely interesting articles by Dr. Shapley, appearing in recent publications of the Astronomical Society of the Pacific, which are preliminary to complete discussions of the observations and results now in process of publication.

Globular star clusters are, as the name implies, symmetrically shaped, globular, in some cases ellipsoidal, systems composed of thousands, possibly hundreds of thousands, of individual stars strongly condensed toward the centre. A few of these clusters are visible to the naked eye as faint patches of light, and the largest of them appear to fill a space in the heavens less than that occupied by the full moon.

The most noted of these are the great cluster in Hercules in the Northern Hemisphere and Omega Centauri and 47 Tucanæ in the Southern Hemisphere. The last named cluster is, in fact, considered by some to be the finest telescopic object in the heavens.

Indeed, the telescope makes a most striking transformation in the appearance of these hazy patches that we strain our eyes to see on a clear night. A most brilliant assemblage of thousands of suns, some deep red, others blue-white, gleam and flicker, some with steady intensity, others with the periodic pulsation of light that is characteristic of the cluster variables.

It is the periodic waxing and waning of the light of the cluster variables that has furnished the clue

to the distances of the globular star clusters, though the results have been checked by comparing the apparent luminosities of other stars in the clusters of the type of the red giant stars, such as Antares and Betelgeux, and of the blue-white type of Vega and Rigel with the known luminosity of these stars at a standard distance from the sun.

The brightest stars in the globular clusters have been found to have a surface temperature two or three thousand degrees less than that of our sun, and to be much redder in color. Emitting as much light as they do, their volume must be very great. They correspond to the red giants of the Galaxy.

The blue-white stars of the clusters are two or three magnitudes fainter than the brightest red stars, and among the bluer of these stars are found the cluster variables which are similar in their light variations to the noted Cepheid variables of the Galactic system. Their light, color, spectrum and velocity in the line of sight all pass through a marked periodic variation in less than a day.

The maximum brightness is more than twice the minimum, but the average brightness for a star of this short period type has been found to be almost exactly one hundred times the luminosity of our

own sun. Between two and three hundred typical variables whose periods range from a few hours to one hundred days have been chosen from five globular clusters, the small Magellanic cloud, and the Galaxy to form a curve which shows that the luminosity of a variable star of this class bears a simple relation to the period of its variation of light.

It has been found that the variables with periods less than one day average one hundred times the brightness of the sun, while those with the longest periods average nearly ten thousand times the luminosity of the sun and are rarely surpassed in brightness by other stars.

The important result of this relationship is that it gives immediately the distance of stars of this type as soon as their apparent brightness and the period of their fluctuations of brightness are known and if the variables are located in globular clusters it gives the distances of the clusters:

Investigations of the light variations of the Cepheid variables in the small Magellanic cloud a few years ago gave a distance of about 33,000 light years for this object, which was about the greatest distance the mind of man was asked to grasp until the measurement of the distances of the globular

clusters was undertaken by the same methods. An apparently hopeless task has at last been accomplished and within the short period of two years the distances of sixty-nine globular star clusters have been measured with a probable error not exceeding twenty per cent. of the values given, which compares favorably with the degree of accuracy obtainable in measuring by direct methods the parallax of our nearer stellar neighbors within a distance of one or two hundred light years.

One-fourth of the globular star clusters measured are more distant than one hundred thousand light years. The two nearest, Omega Centauri and 47 Tucanæ, are a little less than 23,000 light years away.

The most distant so far known has a parallax found by one method to be .000015 seconds, and by another method .000014 seconds. Either value would place it at a distance from us of considerably more than 200,000 light years.

Possibly before the human race appeared upon this planet the light that now reaches our eyes from the most distant globular clusters had started on its journey.

The individual stars visible in the globular clus-

ters, though actually from 100 to 10,000 times more brilliant than our sun, appear extremely faint because of their great distance. Their apparent magnitudes usually average from the twelfth to the seventeenth, while the twenty-first is the limit of visibility of the greatest telescope. Were our sun in the nearest of the globular clusters it would be too faint to be visible. The stars that gleam faintly in these clusters are the giant suns of their systems.

How many more there are too faint to be seen is unknown. The diameters of the globular clusters average several hundred light years. There is nothing in the neighborhood of our sun to compare with this dense crowding of huge suns into a comparatively small space. Within a distance of thirty-three light years of the centre of one typical globular cluster there are to be found 15,000 stars one hundred or more times brighter than our own sun.

Within the same distance of the solar system there are known to be but four or five such stars. Yet these individual stars in clusters are separated by distances comparable to the distance that separates our own sun from Alpha Centauri, more

than four light years away, and no collisions between stars in globular clusters have yet been recorded, though, of course, all individual members of the system are in motion.

The distribution of the globular clusters with reference to the plane of the Galaxy or Milky Way is most striking. Of the sixty-nine clusters examined (and the survey is considered complete within one hundred thousand light years of the sun), thirty-two are north of this plane and thirty-seven south of it, and the average distance of the clusters from the plane is about twenty-two thousand light years. The centre of the system of clusters lies in the Galaxy in the region of the dense star clouds of Sagittarius and the diameter of the system is at least three hundred and twenty-five thousand light years, since two known clusters are separated by this distance. The distance of our local group of stars from the centre of this enormous system is about sixty-five thousand light years.

A significant characteristic of the system of globular clusters, Dr. Shapley points out, is the equatorial belt between 10,000 and 12,000 light years wide within which no globular clusters are to be found. Within this belt are nearly all the

stars listed in our catalogues, including the stars visible to the naked eye as well as the gaseous nebulæ, diffuse nebulosities and open star clusters. Outside the belt are the globular star clusters, the Magellanic clouds, a few isolated stars and probably the spiral nebulæ.

The explanation offered for the avoidance of the equatorial belt by the globular clusters is their inability to form and exist as compact organizations in such an intense gravitational field.

The conclusions drawn from the facts so far discovered are that all known objects in the heavens belong to one enormous unit. The globular clusters, Magellanic clouds and probably spiral nebulæ as well, though vast systems composed of thousands, possibly hundred of thousands, of stars, and moving through space with velocities of a higher order than the average stellar velocity, are, nevertheless, subordinate members of an organized system whose form and extent the globular clusters roughly outline.

The volume of this vast organized system is more than 100,000 times that formerly assigned to the stellar system.

The present location of our solar system in the

universe is about three hundred light years from the centre of a loosely formed moving star cluster which lies just north of the plane of the Milky Way and about half way from its centre to its edge.

Man no longer places himself at the centre of the universe, but finds it 65,000 light years away.

CHAPTER XXX

THE LIFE OF A STAR

THE discovery of radioactive substances has radically affected many astronomical theories bearing not only upon the age of the sun and its planet family, but also upon the evolution of the stars in general and the periods of time required for the various stages of their development.

It is believed, moreover, that there are certain properties of matter, as yet unknown as the revolutionizing properties of radium were unknown until the end of the nineteenth century, that will solve the great problem of the source of the radiant energy of the stars and explain why these bodies pour forth into space light and heat and life-giving energy at a lavish rate that has shown no signs of abatement during hundreds of millions of years.

It is now known, thanks to the irrefutable evi-

dence furnished by radio-active substances, that certain rocks containing uranium and the products of its disintegration, helium and lead, have been in existence for at least 1,500,000,000 years. How long prior to this date our planet earth possessed a surface crust is not known.

According to the testimony of geologists based upon examination of the oldest fossil-bearing rocks, well differentiated forms of life were in existence on our planet a billion years ago.

During this inconceivably long interval of time, according to astronomers, our sun must have maintained its energy of radiation virtually constant though possibly varying cyclically within narrow limits, for any marked increase or decrease in the radiant energy of the sun would have made impossible the continuous development of the various forms of life that we know has taken place during this period.

This fact has a direct bearing on the evolution of the stars or their transition from one type to the next. It is generally assumed that the helium or bluish-white stars are the youngest and that they change gradually to the next type, the hydrogen or white stars, then to the yellow or solar type and

finally to the orange and red stars that are approaching extinction.

The transition from one type to the next in order is supposed to be attended by a decided though gradual decrease in the light and heat-giving power of the star that amounts to several hundred per cent. and would be fatal to life upon any possible planet system of the star.

Astronomers have found from a consideration of all known sources of energy, including radio-activity, that twenty-five million years is all that can be allowed for the evolution of our sun from a nebular state through the various spectral types to its present condition, that of a star in the zenith of its development.

This conclusion is, of course, not at all in accord with any of the observed facts either of astronomy or geology and simply shows that the true source of the energy of the stars has not yet been discovered.

Whatever the source of the solar energy may prove to be, it has been sufficient to keep the spectral type of our sun and its light and heat unvarying, except within comparatively narrow limits, for at least one billion years.

For this reason astronomers are inclined to believe that the gradual transition from one star type to another, granted such a transition does take place, is a matter of hundreds of millions rather than millions of years.

Since primitive forms of life first appeared upon earth, our sun and its satellites have travelled more than 100,000 light years, that is, as far as light would travel in 100,000 years with its unimaginable velocity of 186,000 miles in a second, and has experienced no catastrophe, though it has doubtless journeyed far and wide through the star streams of the Milky Way and seen the apparently immovable constellations fade away in the distance and new groupings take their place.

Though our own particular sun has so far escaped catastrophe the sudden appearance of Novæ is proof that all stars do not pursue the normal course of evolution. As measured by man's standards of time temporary stars or Novæ appear infrequently.

Novæ of startling splendor such as Nova Aquilæ of the year 1918 are to be looked for only at intervals of many years, running at times into centuries, but less conspicuous temporary stars appear on

an average of one in every three or four years. Many of these do not even attain visibility to the unaided eye at their best, but this is probably due rather to their comparatively great distance than to marked deficiency in actual luminosity at the time of their outburst.

Since a year is but a moment in the life of a universe, Novæ are by no means rare phenomena aside from man's point of view. Since the time when life on our planct was in its early infancy, possibly 1,500,000,000 years ago, 400,000,000 temporary stars have burst forth, if the present rate of their appearance was maintained in the past.

Four hundred million celestial catastrophes have been enacted during this period. Nova Aquilæ No. 3, the famous temporary star of 1918, has undergone in a few short months rapid and irregular transitions of type such as normally would require hundreds of millions of years if we judge by the apparent permanency of type of our own sun during the past 1,500,000,000 years.

At first appearance a brilliant blue-white star of helium type, Nova Aquilæ later appeared as yellow as Capella and at another time more reddish than Aldebaran, a late type star, though no regular pro-

gression of type occurred, the changes being fitful and irregular. Little is known yet concerning the origin of Novæ.

According to a suggestion of Prof. William H. Pickering, Novæ may arise from the impact of a body of planetoidal dimensions with a star, assuming that groups of such bodies are possibly drifting through space in great profusion and the various members are separated by many millions of miles. In the regions of the Milky Way, where the star material occurs in greatest profusion, encounters would be most apt to occur.

There is the possibility, according to certain astronomers, that our sun may have acquired part of his planet family by capture. Our planet must have possessed a surface crust for nearly two billion years at least. It has been proven that its interior is not viscous, but as rigid as steel, and is probably composed of material very closely resembling meteorites in composition.

The discovery of radio-active substances has exploded the idea that the only source of the inherent heat of the earth is its originally high temperature and that it is simply cooling off from a molten beginning.

The earth's temperature increases about one degree in temperature for every 100 feet in depth. This was formerly believed to indicate that the earth was cooling off gradually. It is now known that this heat arises from the disintegration of radio-active substances in the earth's crust, which sets free an enormous quantity of heat.

It has been estimated also from the amount of heat generated by these radio-active minerals at the surface that the radio-active layer of rocks probably extends only to a depth of thirty miles. Beneath this crust, it is believed, there lies to a depth of several hundred miles material similar to the stony meteorites in composition, while the earth's central core is of metallic composition, resembling that of iron meteorites and is entirely free from radium.

There is apparently nothing either in the present composition of the earth or in its past condition throughout a period of over a billion and a half years to particularly favor the idea that it once formed part of a primitive solar nebula. Neither is there reason to believe that the sun itself was appreciably nearer to a nebular condition a

billion and a half years ago than it is in the present age.

There is a possibility that the fate of a Nova may await our own sun. Its journeys through the universe may at some future time carry it through the more densely crowded portions of the Milky Way, where some dusky mass may chance across its path and suddenly terminate in a flaring outburst of light and heat the long career of the beautiful yellow star that has so long supplied its planet family with life-giving energy.

Under such circumstances all forms of life on its satellites would be extinguished in the twinkling of an eye. Barring this celestial catastrophe, all present indications point to a future existence for our little planet for many hundreds of millions of years under the genial rays of a constant sun.

CHAPTER XXXI

STELLAR EVOLUTION AND THE "MISSING LINK" STAR

MANY light years distant from the earth, in the vicinity of the Milky Way, is to be found a class of stars remarkable for their deep red color. If Sirius and Vega are the diamonds among the celestial jewels, then these unusual stars are the garnets and the rubies.

For many years these carbon stars or Type N stars, as they are technically called, appeared to have no place in the evolutionary system of the stars. A sequence in the development of all other classes of stars had been well established, which we will briefly outline in order to show the relationship of the carbon stars to stars of other types.

Beginning with the gaseous nebulæ, the accepted order of stellar evolution is from nebulæ to extinct stars through a continuous series of changes, the

first change being made from nebulæ to bright line stars, whose type of spectrum consists chiefly of bright bands of unknown origin and a few bright lines of hydrogen upon a faint, continuous background of rainbow color.

These stars are spoken of as the Type O stars or the Wolf-Rayet stars, and they occur almost exclusively in the Milky Way. The faint, continuous background implies the presence of gases under high pressure, which form the growing nucleus of the star, while the bright lines and bands emanate from incandescent gases under low pressure surrounding the stellar core or possibly gases under strong electrical excitement.

Gradually this type merges into the Orion, or Type B, stars, in whose spectra the bright bands have disappeared. The bright hydrogen lines begin to diminish in intensity and gradually fade away and the dark lines of helium and hydrogen appear. This type is often called the helium type, because of the prominence of the lines belonging to this element. The continuous background is particularly rich in blue and violet light, which gives the stars of this class their beautiful blue-white color.

Rigel is a magnificent star of the Helium or Orion type. The increase in the number of dark lines in the stellar spectra from this point on implies that the gases in the stars' atmospheres are now absorbing more and more from the source of light beneath the rays of the elements of which they themselves consist, according to one of the first laws of spectrum analysis.

The dark lines are for this reason often spoken of as absorption lines, and they appear dark only by contrast with the brilliant background of continuous light upon which they are projected. As the composition of the stellar atmosphere changes with the advance in evolution, absorption lines and bands and flutings of various different elements appear, but to a given element always belongs the same set of lines and its own position in the spectrum.

As the Orion, or Type B star, gradually changes to the Sirian or Hydrogen type, the lines of helium diminish in intensity, while the hydrogen lines increase and finally become the most conspicuous feature of the type. Technically this group is referred to as the Type A stars. The name Sirian is given to it also from the fact that the most bril-

liant of all stars, Sirius, is an illustrious member.

These stars are noted for the intense whiteness of their light and their high temperatures, as well as the low density of their atmospheres. In this class the metallic lines of the solar spectrum also begin to appear faintly, and in the succeeding type known as the Calcium, or F type, they show more strength, though they still remain inferior to the hydrogen lines. The calcium lines have become conspicuous and characterize the type.

Canopus is a most noted member of this group. The color of the stars from this point on is tinged more and more with yellow. The next step in stellar evolution is that occupied by our own sun. Stars of this class, are called Type G stars. In these the hydrogen lines are still very conspicuous, but equalled in intensity by many of the metallic lines, which now appear in great numbers.

Capella is also a prominent member of this class. This stage probably represents the zenith of stellar development, the middle-aged period of star life. From this point the stellar spectrum becomes more and more reddish as the rays of shorter wave length become absorbed more and more in the gases of the

star's atmosphere, which is gradually increasing in density.

Type K, that immediately follows the solar type, is characterized by spectra in which the hydrogen lines are now becoming fainter than some of the metallic lines. These stars are orange in color. An illustrious star of this type is Arcturus. Even before this stage there is manifest a marked tendency of the stars to divide into giants and dwarfs, which becomes still more pronounced in the following class of red stars of Type M, which comes at the end of the process of evolution.

The dwarfs of this class are so feebly luminous that they seem to mark the last stage before extinction and the advent of dark stars.

A decided decrease in the star's temperature is evidenced by the appearance of flutings and bands in the spectrum, due to metallic compounds, chiefly of titanium oxide. Though it is generally considered that the dwarf red stars of this class are nearing extinction, many believe that the giants of Type M, of which Antares and Betelgeux are well known examples, are stars of low density that are gradually increasing in temperature and passing through the evolutionary process in reverse order.

After reaching the white-hot hydrogen or helium stage it is held that they will pass once more through the solar stage to the type of dwarf red stars.

Though the direction of progression through the various types is a matter of some uncertainty for certain stars, the fact that there is a gradual change in the life history of the average star as outlined above appears to be beyond question. Type merges into type through gradations so slight that it is difficult to say where one type ends and the next begins.

Until recently stars of the carbon type apparently had no place in this scheme of evolution. A gap seemed to separate them from stars of other types. Though presenting some points of resemblance to the red stars of Class M, they presented as many points of difference. Both in general distribution in the heavens and in type of spectra they refused to be classified with the M stars.

The carbon stars are all extremely faint stars, due to their tremendous distance from us, even the brightest of the class being barely visible to the naked eye. They show a most marked preference for the plane of the Milky Way, never being found

at any great distance from it, while the red stars of Type M are noted for their nearly uniform distribution in space, being found as often near the poles of the Milky Way as in its plane.

Some of the M stars are our close neighbors, while the brightest of the carbon stars show no parallax or motion across the line of sight. Their spectra are characterized by the presence of dark bands due to carbon compounds, which fade away toward the blue end of the spectrum, while the spectra of the M stars have bands of titanium oxide sharply defined on the violet side and fading toward the red.

In recent years the carbon stars have been carefully studied, and it now appears to be well established that they can be traced back in evolution to stars of the same type as the sun along an independent branch.

The discovery of a new type of star, called Type R, that appears to come intermediate in development between the solar and carbon stars, possessing some of the characteristics of each, has led to this conclusion.

Stars of this new type supply the missing link necessary to trace the development

of a solar star into a carbon star, or possibly the reverse.

Spectra of more than sixty stars belonging to this intermediate class have been investigated. Many of them were formerly classified as carbon stars, though some have a decidedly yellowish tinge and partake strongly of the features of the solar stars.

There are then two paths that a star may follow after it has reached the point in its development known as the solar stage. Differences in the relative amounts of certain elements in the atmosphere of stars may determine which path shall be followed after this point, whether a star shall pass through Type K to a red star of Type M, whose spectrum is dominated by compounds of titanium oxide, or through the new Type R stars to red carbon stars, whose spectra show the distinctive bands of carbon compounds.

That the carbon stars can be linked to the evolutionary chain of stellar development is particularly satisfying to the astronomer, for it shows that all stars can be included in one great system of evolution and pass from one type to the next gradually as they increase in age and development.

CHAPTER XXXII

DWARF STAR HOTTER THAN THE SUN

THE existence of a tiny body two or three hundred per cent. hotter than the sun, yet with a diameter only one-hundredth as great, situated only thirteen light years distant from the earth, and, therefore, one of our nearest stellar neighbors, is a most interesting recent discovery of astronomy.

Van Maanen, of the Mount Wilson Solar Observatory, noted the extremely high proper motion, or motion across the line of sight, of this star, and concluding, therefore, that it was most probably comparatively near to our solar system, made a determination of its parallax from a series of sixteen photographic plates.

The value found, two hundred and forty-four

thousandths of a second of arc, is very large, the greatest parallax known, that of Alpha Centauri, the nearest star, being only seventy-six hundredths of a second. There are in all hardly a score of stars that have larger parallaxes than this small body and are, therefore, nearer to us.

The motion of this star across the heavens is also exceptionally great, amounting to slightly over three seconds of arc a year. It is, therefore, the most rapidly moving star discovered since Barnard's Runaway Star of 1916, which is also a very near neighbor of ours, six light years distant and a very faint body as well, possessing only five ten-thousandths of our own sun's brightness.

It is, however, a whole stellar magnitude, or two and a half times brighter than the newly discovered sun, which has, accordingly, only one five-thousandth part of the luminosity of our own sun and is one of the faintest stellar bodies known.

The most surprising fact discovered about this diminutive sun is that its faintness is due to its extremely small size and not to failing light. This is known from the fact that its type of spectrum is the Calcium or F type, which belongs to bodies at least two or three times hotter per unit area than

our own sun. The color of this small sun has also been determined and is white, indicating a high surface temperature.

Since the light-giving power of this star relative to the sun is known, and since it radiates two or three times more brilliantly per unit area, it is possible to determine the actual size of its radiating surface and therefrom its diameter relative to the sun's diameter.

This diameter is found to be approximately one-ninetieth of the sun's diameter, or nine thousand five hundred miles. As far as size goes, it might, therefore, take its place among the smaller satellites of our sun, the terrestrial planets Earth and Venus being scarcely inferior to it in size. Yet this dwarf sun rushing through space is intrinsically a far hotter body than our own sun, judging from its type of spectrum.

Strange to say, the mighty Canopus, estimated to be at least ten thousand times more brilliant than the sun, has identically the same type of spectrum.

Since the dwarf sun recently discovered has only one five-thousandth part of the light-giving power of the sun, we have here two stars of iden-

tically the same temperature per unit of surface area, differing at least fifty million times in luminosity. Such is the disparity existing in the actual sizes of the suns of the universe!

The only escape from the above conclusions would lie in considering that stars with identically the same type of spectrum do not radiate with equal intensity. It is assumed to be one of the fundamental laws of spectrum analysis, however, that two bodies with identical types of spectra radiate with equal intensity per unit of surface area.

How such a tiny sun could continue to radiate light and heat at the lavish rate indicated by its type of spectrum for any great interval of time is a problem. Most faint stellar bodies so far discovered in the vicinity of the sun belong to the group of nearly extinct dwarf stars low in surface temperature and decidedly reddish in hue. This brilliant little sun of calcium type, whiter and hotter than our own sun, is a marked exception.

It is by far the smallest body of its type so far discovered. In absolute magnitude it is exceeded by all known stars with the exception of a faint companion star of Alpha Centauri. It is possible that this tiny sun may possess still more diminutive

satellites of its own and dispense its light and heat-giving rays to these smaller bodies.

Within our own solar system, at least, it is the exception rather than the rule for bodies to be unattended by satellites. Were this small sun attended by any body at all comparable to it in size, however, its presence could be detected by its disturbance of the bright body.

How many of these suns of planetary size exist in the universe it is impossible to estimate. It is only the very nearest of such stars that can possibly be detected. At a distance of only thirteen light years the star discovered is invisible in small telescopes. Were it much further removed, it would be invisible even in large telescopes. Millions of these diminutive suns may exist in far distant parts of the universe, hopelessly beyond our reach. It is only the light of exceptionally large suns that reaches our eyes from far distant realms.

Since the number of stars of the thirteenth apparent magnitude to which this sun belongs is estimated at something like two million, it can be judged that only through some marked peculiarity would such a star be singled out for observation.

In general the faintness of a star is assumed to

be an indication of great distance. Very distant, faint stars appear immovable in the heavens, though they may be in reality in rapid motion through space. It is, therefore, convenient in many kinds of astronomical work to determine the position of some object under observation relative to one of these fixed ''landmarks'' of the sky.

It is only occasionally, as in the present instance, that one of these points of reference shows any individual motion and thereby calls attention to its unusual nearness. In observing the stars the astronomers have given their attention first to the more brilliant and conspicuous stars. The fainter and less noticeable stars have received less attention and have largely escaped detailed investigation because they are far more numerous than the brighter stars and to examine them with anywhere near the same degree of thoroughness is a manifest impossibility.

The brighter a star the more likely it is to be classified and studied. It is only in recent years with the advent of powerful telescopes and photographic methods of observations that the careful study of the fainter stars has been undertaken at all exhaustively. Interesting and important facts

regarding the fainter stars are now being slowly accumulated in spite of the fact that their numbers run into the millions and they are observable only with the larger instruments.

The importance of the discovery of all facts possible concerning the smaller as well as the larger suns of the universe is very great, since by this means light is thrown upon many puzzling problems associated with the origin and evolution of the stars, the source of their energy and their varied physical characteristics as well as their numbers and distribution through space.

It is a decided addition to astronomical knowledge to know that it is possible for a body no larger than our own planet Earth to maintain a surface temperature far hotter than the sun, though how this tiny sun keeps up its tremendously high temperature is inconceivable unless there is assumed to be some unknown source of the radiant energy of the stars.

CHAPTER XXXIII

PHOTOGRAPHY OF THE HEAVENS

THE photography of the heavens has become of such importance in all branches of astronomy that there is hardly an observatory to-day that is not provided with facilities for carrying on this valuable work.

Every year hundreds of photographic plates are exposed in the study of celestial objects, and probably not a day passes that the sun is not photographed at a number of observatories all over the world. The discoveries already made by photography have more than repaid the efforts that have been made to bring celestial photography to the highest degree of efficiency. Since the photographic plate is particularly sensitive to the violet end of the spectrum, every advantage has been taken of this fact, and by means of specially dyed

plates it has also been possible to photograph beyond the visual limit, even in the red end of the spectrum.

In astronomical photography the telescope takes the place of the camera and the photographic plate takes the place of the observer at the eye end of the telescope.

It is of the greatest importance in such photographic work to accurately compensate for the effect of the earth's rotation on its axis, and this is done by means of the clockwork that is connected with all large telescopes, so that the axis of the telescope may be given a motion opposite to the direction of the earth's rotation. In this way all objects in the field of view are kept immovable with respect to the eye or photographic plate, and the telescope "follows" the object in its apparent westward motion. Anyone who has looked through a telescope when the clockwork is not running knows how rapidly an object will drift out of the field on account of the earth's rotation. It is customary when photographs of the heavens are taken to follow the object with the eye as well, by means of a visual telescope attached to the photographic telescope. By this means any slight irregularity of

motion can be at once detected and corrected for during the time of exposure. In exposures of several hours' duration the rate of the clock might affect the motion of the telescope sufficiently to render the photograph worthless. Exposures of four or five hours are frequent, and in the photography of a magnificent spiral nebula in Canes Venatici, made at the Mount Wilson Observatory, an exposure of more than ten hours was given.

In photographing comets which have a perceptible motion of their own during the time of exposure the telescope is made to "follow" the comet, that is the comet is held immovable in the field of view of the telescope, and star images in the field then appear as short trails of light instead of the sharply defined round dots they would otherwise be.

Excellent comet photographs have been taken since photography of the heavens has become general and research work into the nature of comets is done now almost entirely by means of photography. A large number of plates are examined and compared and the entire history of a comet can be studied in this way from the time when it appears as a faint nebulous object, through the interesting

phase when it is approaching or receding from the sun and developing an extensive tail, until it again departs into the depths of space. It can be detected on the photographic plates long after it is beyond the reach of the most powerful telescopes visually.

Many comets as well as asteroids and faint satellites are now discovered by photography. Plates are exposed to various parts of the heavens where the existence of such objects is suspected and the earth's motion is exactly balanced by means of the siderial clock so that when the plates are developed each star registers its position by a clear, sharp dot proportional to its brightness. If any moving object is within the field it will appear on the plate as a short trail of light proportional in length to its motion during the time of exposure. In this way it is easily distinguished by its appearance. A host of asteroids have been discovered by this method and the some comets are found in the same way. Halley's comet at its return in 1910 was first detected upon the photographic plates. Objects too faint to be seen in the largest telescope will cast enough light upon a photographic plate in several hours' exposure to reveal

their presence in the heavens. Several satellites discovered photographically have never been seen except on photographic plates.

These are too faint to be visible to the human eye aided by the most powerful telescope, and we owe to photography alone our knowledge of their existence. The eye surpasses the camera, however, in observation of the finest details of planetary and lunar phenomena, and it has been said that photographs taken with powerful telescopes do not show the detail observable visually.

The study of all solar phenomena has been considered of such importance that there now exist observatories that make this their chief work. A noted observatory of this class is the Mount Wilson Observatory at Pasadena, Cal. Wonderful progress has been made here photographically. The spectro-heliograph was invented here by Dr. Hale and is a device for photographing the sun by the light of a single wave length such as a calcium or hydrogen ray. The spectro-heliograph acts as a screen to cut off all light except that of a certain line in the spectrum, and extremely valuable and interesting photographs of the sun have been obtained by this method.

On total solar eclipse expeditions the photographic outfit is of prime importance. At this time only is it possible to obtain photographs of the mysterious corona that is only one-tenth as bright as full sunlight and therefore masked at all other times by the glare of the sun.

A striking instance of the value of photography to astronomy is the discovery made by Prof. Barnard through the examination of photographic plates of a star of the eleventh magnitude in the constellation Ophiuchus that has the enormous motion through space of at least ten seconds of arc a year. This puts it first in the class of "runaway stars," which, according to the late Prof. Newcomb, have a motion that not all the matter in the universe could control. The greatest known annual proper motion, as it is called, has been 8.7 seconds until the discovery of this star, but very few stars are known that have a proper motion greater than one second, and the average is far below one second. This discovery was confirmed by the study of photographic plates at Lick and Harvard dating back as far as 1888. We have here a specific case of the value of photographic records.

The astronomers of to-day are storing away

THE CORONA OF THE TOTAL SOLAR ECLIPSE OF MAY 17, 1901

(Drawn from the negatives by H. R. Morgan)

upon photographic plates material that will lead to the discoveries of the future. If such valuable records could have been left to us by our ancestors the knowledge of the wonders of the heavens would be advancing to-day by leaps and bounds. In all research work into the nature and structure of the universe photographic records are invaluable. By comparison of plates taken many years apart changes become evident. It is believed that nebulæ may possibly change greatly in form in the course of a few hundred years and that the brightness of many stars, aside from the class of variables, may have changed appreciably in this time. Photography is by far the best means of solving such questions as well as many others of a similar nature. Four-fifths of all spectroscopic work, it is estimated, is now done photographically and done far better than it would be possible to do it visually, owing to the light gathering power of the sensitive plate. Spectra of stars that would never be seen otherwise can be detected by this means.

Last but not least is the fact that the wonders of the telescope, the nebulæ, star clusters, planetary markings, corona and numerous other equally interesting phenomena would never be seen except by

a few if it were not for photography. At the different observatories in this country, Lick, Harvard, Yerkes, Mount Wilson and many others, not to mention those abroad, magnificent photographs have been taken which are at the disposal of all of us through our schools and libraries. To be sure the result may be that many of us are only the more desirous to see for ourselves the beauties of the heavens and to explore the depths of space, and it is to be hoped that the day may come when each city will have an observatory at the disposal of all who may care to use it. It is surprising what even a six-inch telescope will reveal and we do not need a 40-inch Yerkes telescope to enjoy the wonders and beauties of the universe.

CHAPTER XXXIV

THE PHOTOGRAPHIC PLATE—THE ASTRONOMER'S EYE

THE astronomer of to-day spends very little time gazing at the stars through the telescope. His place at the eyepiece has been taken by that silent sentinel of the sky, the photographic plate, which is on duty in some instances for hours at a time gathering precious rays of light from star or nebula that the human eye would search for in vain. We find the modern astronomer oftener in the dark room, the physical research laboratory, the instrument shop or the computing room than at the telescope. His discoveries are now rarely made by direct observation of the heavens. They result chiefly from careful examination and measurement of photographs.

Photographs taken on June 7, 1918, at the Harvard College Observatory, where the photography

of the heavens is carried on regularly and systematically every clear night, show that the initial stages in the rapid increase in brightness of the magnificent new star of 1918, Nova Aquilæ No. 3, were recorded by this means even before the star became visible to the naked eye. When the brilliancy of the nova on the night of June 8 amazed all observers the astronomer's first thought was to obtain photographs as quickly as possible of both the star and its spectrum and then examine its past history. This, it was found, had been recorded for fully thirty years on photographic plates stored away at the Harvard Observatory, where many a valuable astronomical discovery has been made by means of photography.

A never failing eye is kept on the heavens in the form of the photographic plate, and changes that take place there hour by hour, day by day or year by year may be recorded for future reference. Photographs taken in our day may be of priceless value to future generations of astronomers, for by comparison of photographs taken at intervals of ten, fifty or one hundred years important discoveries may be made concerning the motions of the stars through space, changes in the

structure of the nebulæ, the appearance and disappearance of temporary stars, and all the varied and wonderful phenomena of a universe of countless suns at all stages of development.

Celestial photography is beset with many difficulties and presents many problems, some dependent upon the nature of the plate and its development, others upon the instrument.

Photographic plates are subject to many imperfections. False stars frequently appear after exposure of the plate. It is not known whether these appear in the process of development or are due to defects in the plate itself. They are usually easily distinguished from true stars, however. In a few rare instances defects in the plate have been taken for asteroids or comets, which usually appear as short trails.

The photographic discovery of an asteroid with a satellite by Prof. Wolf of Heidelberg, announced in the spring of 1918, caused considerable interest at the time, as it was most unusual and unexpected. Diligent search by other astronomers and the examination of additional plates taken of the same region failed to confirm the discovery, and it was finally decided that the "satellite" was possibly

an imperfection of the photographic plate, though the discovery of the asteroid was confirmed.

The photographic images of the stars are not of uniform shape and density all over the plate. They are usually perfectly round and of even density in the centre of the plate, but near the edges they are elliptical or elongated and irregular in density, a fact that makes their accurate measurement very difficult. Star images are, in fact, affected by many different factors, depending upon the kind of plate used, length of exposure, temperature and developer, as well as the telescope itself, whether reflector or refractor, of short or long focal lengths.

It is a well known fact, however, that the sizes of the star images on the same plate vary with the brightness of the stars photographed. The brighter the star the greater the diameter of its image on the plate. This affords a method of determining the relative brightness of the stars photographically that is more accurate than the visual method. The human eye is more liable to error than the photographic plate, since the individual peculiarities of the eye are many and subject to great uncertainty. Another advantage of the photographic method for finding the relative brightness

of the stars lies in the fact that stars too faint to be seen appear on the photographic plate even with an exposure of short duration, while a longer exposure brings out additional stars.

The photographic plate, as is well known, is particularly sensitive to rays of short wave length, the blue and violet rays, while the eye is, on the contrary, susceptible to the rays of long wave length, the red, orange and yellow rays. A very important application of this principle is made in determining the color of stars so excessively faint that they cannot be studied with the spectroscope. The physical condition and stage of development of a star are closely associated with its color and therefore any knowledge that may be gained in regard to the color of faint stars will add materially to our knowledge of them.

If an excessively faint star appears much brighter photographically than it does visually it is evident that it is particularly strong in blue or violet light; that is, it is an early type or young star. On the other hand, if the star is fainter photographically than it is visually it is strong in red or orange light, to which the eye is particularly sensitive. Such a star is a red or late

type star. This difference between the visual and photographic brightness of a star is called its color index, and it is of great value in classifying faint stars, the only clue in fact that the astronomer possesses to their age and physical condition. It indicates the relative proportions of light of different wave lengths emitted by the star and the nature of its atmosphere.

By the use of specially dyed plates or color screens it has become possible to shut off the rays of violet or blue light from the photographic plate and make it sensitive to the same rays that affect the eye. In this way the photographic plate becomes the equivalent of the human eye with the added advantage of being free of the individual peculiarities of vision that make visual estimates of the relative brightness of the stars so uncertain. The stellar magnitudes determined with these specially prepared plates are spoken of as photo-visual magnitudes.

The relative magnitudes of the stars are thus expressed in three different scales, the visual, the photo-visual and the photographic. The first two should be approximately equal. The photography of the heavens with the photo-visual rays opens a

comparatively new field of investigation and experiments with various methods of dyeing plates or screening off certain rays may yield some valuable results in the future.

CHAPTER XXXV

THE STORY OF A RUNAWAY STAR

THE recent discovery of a rapidly moving star in the constellation Ophiuchus aroused considerable interest in the astronomical world. The unusual motion of this star was detected by Prof. Barnard at the Yerkes Observatory in 1916 from a comparison of a series of photographs taken at Yerkes and reaching back as far as 1894. It was confirmed by numerous plates taken at Harvard Observatory, the earliest of which dates back to 1888.

In one year this star moves about twice as far as the average star does in a century. It has the enormous proper motion, that is, motion perpendicular to the line of sight or across the sky, of 10.3 seconds a year. If a star moves two-tenths of

a second a year it is considered to have a large proper motion.

So slight is the change in the relative positions of the vast majority of stars from year to year that after the lapse of a thousand years the skies are practically the same in their general appearance.

The smallest displacement that a keen eye can detect in the position of a star when unaided by a telescope is three minutes of arc, and the average cross motion of a star in a thousand years does not exceed one minute.

The extremely few stars that form notable exceptions are generally spoken of as "runaway stars." The faint star in the southern hemisphere known only by its catalogue name of Cordoba Zone 5th No. 243 formerly headed the list of runaway stars with a proper motion of 8.70 seconds, and next in order is the famous runaway star Groombridge, 1830, with a cross motion of 7.07 seconds.

So rapid is the motion of Barnard's star that it will cover an arc of fully three degrees, just the length of the belt of Orion, in a thousand years. If the majority of stars had a motion at all comparable to this the appearance of the constella-

tions would be entirely changed in a few centuries. If the two stars spoken of as the "Pointers" in the Great Dipper had a proper motion as high as ten seconds a year this famous constellation would lose its distinctive shape in considerably less than a thousand years.

Many stars have a common drift through space, but it is very rare for all the chief stars of a constellation to share the same direction of motion. Of the seven stars that form the outline of the Great Dipper five are moving in the same direction, but the brighter star of the Pointers and the star at the end of the handle are moving in an entirely different direction.

In the short time that has elapsed since its discovery determinations of the parallax, radial velocity and type of spectrum of the new star have yielded some interesting results. As seen in the 36-inch Lick refractor it is a faint, orange-colored star of the 10½ magnitude, and it has the type of spectrum that is characteristic of stars far advanced in evolution. It is what is known as a "dwarf" star of the type M. The variable star Alpha Herculis is a "giant" of the same class. The spectra of stars of type M are strangely fluted

in appearance, because of the presence of titanium oxide. It is not known as yet why stars of this type show spectra so dominated by this one substance.

The shifting of the lines of this star's spectrum toward the blue indicates that it is approaching the solar system, and measurements of the amount of this shift indicate a rate of approach in the line of sight of about sixty miles a second. It is a well known fact that if a star is receding from the earth the lines of its spectrum shift toward the red end of the spectrum and if it is approaching they shift toward the blue. So it is by the measurement of the lines in this star's spectrum that we can tell it is coming toward us at the rate of sixty miles a second.

Some determinations of the parallax of this star have been made, and apparently it is the largest known, with the exception of the parallax of Alpha Centauri, the nearest star. In other words, Barnard's new star is probably our second nearest neighbor, and, its brightness is found to be five ten-thousandths that of the sun, which makes it one of the faintest stars so far known.

It seems to be characteristic of "dwarf" stars

of this type to have high velocities. There is a decided tendency for stars to increase the speed of their journey through space as they increase in age, although such a velocity as this star possesses is far above what we should expect of a star of its class. It seems to be a true runaway star. Since faint stars have not yet received as careful scrutiny as has been given to the brighter members of the stellar system, possibly we may find in time that there are faint stars nearing extinction that travel through space with a velocity far exceeding any to which we have been accustomed.

It is a peculiar fact that nearly all types of stars show a tendency to crowd toward the plane of the Milky Way. Type M, to which the newly discovered star belongs, is a noted exception to this rule. Stars of this type show a spherical distribution of space and are just as likely to be found at the poles of the Milky Way as in its plane. It has been suggested that dwarfs of this type with extremely high velocities such as Barnard's star possesses may have acquired their enormous speed while falling in toward the plane of the Milky Way from great distances without.

Runaway stars have also been spoken of as

visitors passing through our stellar system from regions beyond. It has been said on good authority that there is not sufficient matter in our stellar system to control the motion of such a runaway star as Groombridge, 1830.

In the short time that has elapsed since the detection of the enormous proper motion of the new star some very interesting facts have been well established. This star is in all probability our second nearest neighbor at a distance of about six light years. Its luminosity is five ten-thousandths of the sun, making it one of the least luminous of all stars so far discovered, and it is, as we would expect, a star of most advanced type, bordering close upon extinction.

CHAPTER XXXVI

MEASURING STAR DISTANCES

THE parallax of a star is its apparent displacement in the sky due to the change in the earth's position in its orbit. It is the angle that 93,000,000 miles, the distance from the earth to the sun, subtends at the star. Viewed from the vast majority of the stars this base-line shrinks to an immeasurable point.

The direct measurement of the parallax of the stars by the triangulation method, by which the star's displacement at different times of year is determined either photographically or visually with reference to faint stars so distant as to have zero parallax, is possible only for a few stars near the solar system. The distances of nearly a thousand stars have been determined with more or less accuracy by this method.

The astronomer is here attacking a problem simple in principle but possessing great practical difficulties due to the minuteness of the angle to be measured. The largest known parallax, which, of course, belongs to the nearest star, is only seventy-eight hundredths of a second. This value of the parallax corresponds to a distance of about twenty-five trillion miles from the earth.

Since to express the distance of the stars in miles would be as cumbersome and meaningless as to express the distance from the earth to the moon or neighboring planets in inches, a new unit for the measurement of stellar distances has been found in the velocity of light. In one second light travels 186,000 miles, in one year it travels nearly six trillion miles. The distance light travels in one year is spoken of as the light year. The distance of over twenty-five trillion miles that separates us from the nearest star is equal to four and one-third light years, and the rays of light leaving this star take four and one-third years to reach the earth.

There are about twenty stars with parallaxes exceeding $0.''2$. A parallax of $0.''2$ corresponds to a little over sixteen light years. There are about

twenty stars known to be within this distance of the sun, and their distances have been determined by direct measurement of their parallaxes with an error that is less than 25 per cent. of the quantity measured.

A directly measured parallax of ".02 has very little value, because unavoidable errors of instruments may be nearly as large as the quantity to be measured. This parallax corresponds to a distance of about 160 light years, and the tremendous extent of the universe can be judged from the fact that scarcely one hundred stars have parallaxes greater than ".02. It is safe to say that no reliable measures of the distances of the stars lying beyond this point can be made by direct measurements of their parallaxes.

The triangulation method is long and tedious and care must be taken to avoid systematic as well as accidental errors. The finally determined parallaxes are usually the result of a large number of independent measurements.

There are a number of indirect methods of finding the parallax of the more distant stars. The most important of these is probably the one that deals with the proper motions of the stars. The

stars are all moving in various directions and at different rates. The actual motion or space motion of a star, as it is called, can be divided into two components. One is the motion in the line of sight toward or from the observer. This is called the radial velocity and can be determined by means of the spectroscope. The other component, the angular motion across the line of sight, is called the proper motion of the star. In general the nearer a star is to the earth the greater will be its proper motion.

While parallax is a displacement in a star's position due to a change in the observer's position as the earth moves around the sun, proper motion is the displacement in the star's position due to its own motion across the line of sight, and, of course, the nearer the star is to the observer the more it appears to be displaced and the greater its proper motion. A star that has no measurable proper motion is at great distance from the earth.

When both the radial velocity and the proper motion of a star are known its distance from the earth can be determined, for its cross-motion then becomes known both in angular measure and miles per second. Moreover, the distances of moving

groups of stars or moving star clusters can be found when the radial velocity of any one star in the group is known, since the stars are all moving at the same rate in the same direction. The extent of the group, in light years, the distances separating individual stars, as well as the distance of the group from the earth, become known as soon as the common proper motion of the stars and the radial velocity of one of the group has been determined.

When the distance of a star is known, its absolute magnitude or luminosity, compared with the sun's luminosity, can also be found from a simple relation between the parallax and the apparent and actual brightness of the star.

Some important results arising from investigations of the proper motions and radial velocities of stars have been the discovery of star drift or star streaming, and the direction and amount of the sun's motion through space as well as actual determination of distances in light years for individual types or groups of stars such as the Cepheid variables, the Orion stars, the giant red stars, the Pleiades, the Ursa Major group, and others.

The motion of the sun through space also fur-

nishes a valuable base line for the determination of the distances of the stars. This motion amounts to nearly four hundred million miles a year and is, of course, increasing year by year. If the motion in one year gives too small a base line the motion in ten years or one hundred years can be used. In applying this method the individual motions of the stars have to be taken into account, but it is customary in computing the average distance of a certain class of stars to go on the assumption that the sum of the individual motions of stars moving in all directions will compensate each other and the result will be the same as if all the stars were at rest.

The average of the motions of a large number of stars across the line of sight will total zero and the average of their motions in the line of sight will be made up of their own motions plus the effect of the sun's motion, which is spoken of as the parallactic drift, since it is used to obtain the parallax of the group in question. When the sum of the radial velocities of all the stars in the group is formed the individual motions of the stars cancel each other and the value remaining represents the effect of the sun's motion on the

group. The amount and direction of the sun's motion is known and so the result gives directly the parallax of the group.

Photometry, or the measurement of the apparent brightness of the stars, is becoming more and more important, since it has now become possible to find the absolute magnitude or light-giving power of stars of certain types independently of their distances. When both the absolute and apparent brightness of a star are known the star's distance can be found, just as when we know the candle power of a given light we can find the distance at which it will have a certain apparent brightness.

Absolute magnitude is the new unit for measuring the light-giving power of suns, just as candle-power is the unit for measuring the light-giving power of terrestrial lights. It is defined as the apparent brightness a star would possess if it were at a distance of thirty-three light years from the earth, which is the distance that corresponds to a parallax of one-tenth of a second of arc. At this distance the sun, which has the value minus 26.7 on the apparent brightness scale, has the value 5 in absolute magnitude. That is, if the

sun were thirty-three light years distant it would appear to be only a fifth magnitude star.

The same scale of relative brightness holds for the absolute magnitudes of stars as for the apparent magnitudes, each unit of magnitude representing a change in intensity in the ratio of 1 to 2½. A change of five magnitudes means a change of a hundred fold in brightness. A star whose absolute magnitude is ten has only one-hundredth of the light-giving power of the sun, but if the absolute magnitude is zero the star is a hundred times brighter than the sun. An absolute magnitude of minus five means the object is 10,000 times more brilliant intrinsically than the sun. It has been found that there is as great a range in the actual or absolute magnitudes of the stars as there is in their apparent magnitudes.

We come now to a most important point, upon which depends the value of the photometric method of finding the distances of star clusters thousands and even hundreds of thousands of light years distant. That is, there appears to be an upper limit to the light-giving power of suns, and, moreover, certain types of stars possess a nearly uniform luminosity, the various stars of the type differing

little among themselves in light-giving power. The brilliant helium stars are all massive stars averaging one hundred times brighter than the sun. The giant red stars are still more luminous. The Cepheid variables, valuable because the periods of their light variations depend on their luminosity so closely that their absolute magnitudes can be determined when their periods are known, are also giant stars. The Cepheids with periods less than a day average one hundred times brighter than the sun, while those of longest period are rarely surpassed in brightness by other stars.

These facts furnish a simple accurate method for finding the distances of the globular star clusters whose brightest stars are helium stars, giant red stars and Cepheid variables. Measuring the apparent brightness of the stars in various clusters and knowing the absolute magnitudes of these same stars, the distances of the globular clusters can be found more quickly and easily than the parallax of a star a hundred or so light years from the earth can be found by the triangulation method and with less error. The average absolute magnitudes for the various types appearing in clusters were obtained originally by the proper

motion or parallactic drift method, using stars of these types comparatively near.

It has been found by this simple method that the globular clusters are the most distant celestial objects known, except possibly the spiral nebulæ. The only limit set for the measurement of the distances of those objects lies in the limit of visibility of the telescope used. There appears, however, to be a thinning out of these objects beyond a distance of 200,000 light years, and it is possible that all the globular clusters in the visible universe are within the reach of telescopes now in use. The 60-inch Mount Wilson reflector shows stars down to the twentieth apparent magnitude. The most distant globular cluster, which represents the greatest distance man has so far measured, is 200,000 light years distant and its brightest stars are of the seventeenth apparent magnitude. A margin of apparent brightness still remains for the measurement of clusters still more distant if they exist.

CHAPTER XXXVI

LAYING STARS IN THE BALANCES

THE weighing of the heavenly bodies, the sun, the planets and the stars, appears a stupendous problem, beyond solution, and so in truth it was until Newton discovered that the law of gravitation is universal and reaches even to the stars.

The same force that holds us to the earth holds the earth in its orbit and sways the components of a double star system. Every particle of matter in the universe attracts every other particle with a force proportional to the product of the masses and inversely proportional to the square of the distance between them. The greater the masses and the less the distance between them the stronger their attraction for each other. It is upon this principle that the weighing of celestial as well as terrestrial objects rests.

If an object were not subject to the attraction of neighboring masses it would travel forever in a straight line. It is the attraction of nearby objects that causes the path to deviate from a straight line, and the amount of the deviation is a measure of the attractive force of the disturbing body.

In travelling eighteen and a half miles in its orbit, the distance passed over in one second, the earth falls about one-ninth of an inch from a straight line in the direction of the sun, and this is a measure of the sun's attraction for the earth.

The earth's attraction for an object at its surface has been determined from observation, and since it is also equal to the earth's mass divided by the square of its radius it is possible to find the mass of the earth in terms of some known mass at its surface.

This has been done a number of times, but the experiment is a very delicate and troublesome one, since the attraction between bodies at the earth's surface is so small that it is measured with great difficulty.

A large metal ball or a mountain of known mass is usually chosen, and its attraction for some

object near by at a measured distance is determined observationally. This attraction is proportional, according to the law of gravitation, to the mass of the body, which is known in this case, divided by the square of its distance from the object attracted.

Comparing this attraction of one known mass for another on the earth's surface with the attraction of the earth for objects at its surface the ratio of the earth's mass to the known mass is obtained. It has been found in this way that the earth's weight is about five and a half times that of an equal volume of water.

This also gives the earth's density, which is simply its mass divided by its volume, the standard of comparison being the density of water.

Since the total weight of the earth averages much more than the weight of the earth's crust, it is evident that the material near the earth's centre is much more compressed and heavier than at its surface, due to the tremendous pressure of the overlying strata of the earth.

Knowing the weight of the earth and its distance from the sun, we are in a position to find the sun's mass in terms of the earth's mass. It follows from

the law of gravitation that the mass of a body with a satellite is proportional to the cube of the distance of the satellite divided by the square of the satellite's period of revolution.

This will apply to the planet's revolution around the sun and that of the moon around the earth. So if we find the cube of the earth's distance from the sun and divide it by the square of the earth's period of revolution, three hundred and sixty-five and a quarter days, we have a number that is proportional to the mass of the sun.

It comes out that this number is about three hundred and thirty thousand times larger than the number proportional to the earth's mass found by dividing the cube of the moon's distance from the earth by the square of its period of revolution around the earth, so it is concluded that the mass of the sun is three hundred and thirty thousand times as great as the mass of the earth.

To find its density compared with the earth's density we simply divide its mass compared with the earth's by its volume compared with the earth's volume, and we find that has only one-quarter of the density of the earth or about one and a half times the density of water. The sun therefore

weighs only one and a half times as much as an equal bulk of water would weigh.

Just as we have found the numbers proportional to the earth's mass and the sun's mass so we can find the numbers proportional to the masses of all the other planets attended by satellites simply by dividing, as before, the cube of the distance of the satellite from the planet by the square of its period of revolution around the planet.

Both of these quantities, the distances and periods, can be determined from observations of the satellites. Comparing, then, the values for each planet with the number proportional to the sun's mass, the mass of every planet that has satellites is found in terms of the sun's mass and also of the earth's mass. The mass of Jupiter and also of Saturn has been found with great accuracy, as both of these planets have a large number of satellites.

Mercury and Venus, on the other hand, are the most difficult to weigh, for they have no satellites. Their masses have been found by observing their attractions for comets and near-by planets which produce "perturbations" in the motions and positions of the attracted bodies. These perturbations

are, according to the law of gravitation, proportional to the masses of the two bodies and inversely proportional to the square of the distance between the bodies affected.

The most difficult body to deal with in the solar system is the moon. The problem of two attracting bodies is easily solved mathematically, or even three bodies if one of them is comparatively very small or very remote, but in the case of the moon we have a satellite that is very large compared to its primary.

As a result there is a problem of three attracting bodies, the sun, the earth and the moon, to consider. The laws controlling the motions of three bodies are as infallible as in the case of two bodies, but the changes in the relative motions and distances of the three bodies are so complex that it lies beyond the power of mathematics to solve the problem completely, and only approximations to the complete solution are possible.

One method for obtaining the mass of the moon is to compare the tide-raising force of the sun with the tide-raising force of the moon. Another is to measure the apparent displacement of the sun in the heavens at half moon due to the fact

that it is the centre of gravity of the earth and moon that revolves around the sun under the laws of gravitation and not the centre of the earth.

This centre of gravity lies, it has been found, within the earth's surface and 2,880 miles from its centre, and it follows as a result of this that the earth's mass must be eighty-one and a half times the moon's mass.

Knowing the relative masses of the members of our own solar system, how can we find the masses of the stars? In the case of single stars this cannot be done. All the stars are apparently moving through space in straight lines. Up to the present time no curvature in the paths of isolated stars has ever been observed. If we were able to trace back the orbits of the stars for some hundreds of thousands of years we might make some interesting discoveries concerning stellar motions; but so far as we know now the stars are travelling in streams or groups along parallel lines to and fro under the general attraction of the entire system of the stars, no star appreciably deflecting the motion of any other.

There are, however, many stars that are not single but consist of two or three, rarely more,

components revolving around a common centre of gravity. These are known as binary or multiple stars, either visual or spectroscopic, and it is possible to determine their combined mass in terms of the sun's mass provided the distance of the binary star from us is known.

This is done in the same way that we compute the mass of a planet that has a satellite. The distance of the companion star from its primary star is found by observation, also the period that the satellite requires to make a revolution around the primary star. Then by the same law of gravitation the cube of the distance of the satellite divided by the square of its period gives the combined mass of the star system in terms of the sun's mass.

In case the centre of gravity of the system can be found observationally the comparative masses of the two stars become known also. Only the masses of the nearest stars can be determined, since the distance of the star system from the earth is needed to solve the problem. The masses of about ten or twelve stars have been determined by this method, and though it is rather unsafe to generalize from such a small number of stars the results seem to indicate, what there is reason to

suspect from other investigations of a different nature, that the masses of the stars average about the same as the mass of our own sun.

To weigh the heavenly bodies is not a simple matter. Many observations and computations are necessary. Since the discovery of the universality of the law of gravitation astronomers have been working on the problem and improving results, and they are not yet at the point where they are satisfied with their results in spite of the fact that the error in the value of the sun's mass is less than one per cent. of the value given. The task of improving the values of the masses and positions of the heavenly bodies falls upon the theoretical astronomer and is usually undertaken by the National observatories or under special grants to individuals fitted to cope with this arduous problem.

CHAPTER XXXVIII

WONDERS OF ORION

ORION, the most magnificent of all the constellations, is visible throughout the greater part of the night in winter. The three bright stars, evenly spaced in a straight line, that mark the warrior's belt and the four brilliant stars in the form of a huge quadrilateral that outline his body are the most distinctive stars of the constellation. They are among the first stars to shine forth after sunset, appearing higher and higher in the eastern sky on each successive evening.

In addition to forming the most impressively beautiful of all the constellations, the stars of Orion, with the exception of Betelgeuse, the deep red star that marks the giant's right shoulder, all belong to a connected system of inconceivably great extent associated with one vast enveloping nebula.

The denser portion of this nebula is known as the "Great Nebula in Orion," considered by many to be the most beautiful telescopic object in the heavens. It covers a square degree in the sky and is associated with the central star in the "sword of Orion," which is formed by a row of faint stars extending in a southerly direction below the belt.

In the midst of the great nebula glows an exquisite little trapezium of stars, two of which are attended by extremely faint companions. It is known as the sextuple star, Theta Orionis. Not far away, connected with the central nebula by a faint nebulous extension, is the triple star Iota Orionis, and the entire constellation abounds in double and multiple stars, many of which are surrounded by nebulous haze.

It is well known that the helium stars, the type to which the Orion stars belong, are not universally distributed in space. They favor certain regions and occur in loosely formed groups or clusters, usually attended by nebulosity. They are the most massive and the hottest of all the stars, and they are never to be found far from the plane of the Milky Way.

Prof. W. H. Pickering has made recent investi-

gations of the distance of the great Orion nebula, and the size and luminosity of the Orion stars. According to his results, this glorious constellation is constructed on a plan of inconceivable grandeur. The distance of the great Orion nebula he has found to be a little over sixteen hundred light years, corresponding to a parallax of ″.002. If we desired to express this distance in miles we would have to multiply sixteen hundred by the value of one light year in miles, or 63,000 times the distance from the earth to the sun, remembering that the distance from the earth to the sun is 93,000,000 miles. According to this same estimate the luminosity of the brilliant blue-white star Rigel, the brightest star in the constellation, is nearly ninety thousand times that of our own sun, while the triple star Iota Orionis mentioned above is fifteen thousand times more luminous than our sun.

Another estimate of the distance of the Orion nebula made recently by Kapteyn places it at a distance of six hundred light years, corresponding to a parallax of ″.0054, and gives the light-giving power of Rigel as nearly twelve thousand times that of the sun and the light-giving

power of Iota as two thousand times that of the sun. If Prof. Pickering's estimate gives approximately the true distance of this wonderful constellation then its brightest star Rigel is a super giant among the stars, unsurpassed in brilliancy by any other star unless we make an exception of giant Canopus, the magnificent star of the Southern Hemisphere.

Astronomers have long held the theory that the helium stars associated with the great irregular nebulæ, such as the stars of Orion and the Pleiades, are being condensed from the nebulæ with which they are associated. The order of evolution has always been assumed to be from nebula to star. In light of more recent knowledge the idea is gradually and persistently growing that in some instances the evolution may be progressing toward the nebula instead of away from it. In other words, the nebulosity surrounding the Pleiades and many of the stars of Orion may have been thrown off from the surfaces of these stars. In the solar corona and the zodiacal light and the tails of comets, it has been suggested, we may see in a slight degree the laws that govern the repulsion of matter, under light pressure and possibly elec-

tro-magnetic forces, at work in our own solar system.

The characteristics of the novæ or temporary stars also give support to this view. Novæ have been seen to change from helium type stars to bright line stars and then to planetary nebulæ, exactly reversing the accepted order of development.

In his discussion of the great nebula and helium stars in Orion Prof. Pickering says: "It was formerly universally supposed that the nebulæ were condensing, but . . . an appearance somewhat similar to the nebula was produced by photographing an explosion of flash powder." C. D. Perrine, writing in the *Astro-physical Journal*, says: "The dark, finely divided matter which is believed to exist in the distant galactic regions may be none other than condensed nebulosity; in place of the early Orion stars, for example, being wholly in the process of condensing from their inclosing nebulous envelope, this nebulosity is, in fact, largely the result of a great catastrophe, the nebulosity having been thrown off in the process." He asks: "Is this also true of the nebulosity in the Pleiades with the difference that in the Pleiades

the stars are slightly 'older' in type and the nebulosity not self-luminous? Has this nebulosity frozen from a gaseous state?"

It is possible, according to Perrine, that the Orion or helium type stars are extremely massive and hot and confined to certain regions as a result of varying external conditions existing in different parts of the universe. Where cosmic matter is dense stars of great mass and high temperature would be found. The energy obtained from the material gradually swept up by these stars would exceed the energy lost by radiation. Their mass and temperature would increase while light pressure and electro-magnetic forces would drive from these stars the lighter gases that form the nebulosity enveloping them.

In parts of the universe where the cosmic matter, either meteoric or gaseous, is less plentiful, the evolution of the stars would be, on the contrary, away from the nebula and toward the later and cooler type stars, culminating in extinct, dark stars following after the dwarf red type stars in evolution.

CHAPTER XXXIX

THE CONSTELLATIONS OF WINTER

AMONG the sparkling brilliants of midwinter skies are three, Betelgeuse in Orion, Sirius in Canis Major, the Greater Dog, and Procyon in Canis Minor, the Lesser Dog, that outline in the heavens a huge equilateral triangle that is as conspicuous a figure in the winter as the Great Square in Pesagus is in early fall.

During the early evening hours of February this massive triangle of first magnitude stars will be found not far from the meridian, the two Dog Stars following closely at the heels of the warrior Orion as with uplifted club he pursues Taurus, the Bull, across the heavens to the westward.

Ruddy Betelgeuse is in the right shoulder of Orion, and not far away to the west glows Aldebaran, the brightest star in the V-shaped group of

the Hyades, also deeply red, representing the baleful light in the eye of the Bull as he charges with lowered head at the warrior Orion.

At no other season is there presented so finely to view such an impressive assemblage of first magnitude stars. Eight of the twenty brightest stars in the heavens are now visible in our latitudes in the early evening.

If we are south of the thirtieth parallel we may also see Canopus of the Southern Hemisphere, second only to Sirius in apparent brightness, the star of immeasurable distance and unimaginable size and splendor that in actual luminosity makes Sirius appear but a dwarf. Ten thousand times the light-giving power of the sun is the lowest limit that can be set for the light-giving power of this supergiant, and it may far exceed this amount.

Sirius, at the southeastern vertex of the triangle, is one of our nearest neighbors in space, and is only surpassed in brightness by the planets Jupiter and Venus and occasionally Mars. Its light takes between eight and nine years to reach our solar system, however, and its distance, if we wish to express it in miles, amounts to about 550,000 times the distance from the earth to the sun.

Sirius is attended by a companion that is one of the most feebly luminous bodies known. Though its mass is about one-half that of Sirius, it would take 20,000 such companions to equal Sirius in brightness. The two stars are separated from each other by a distance of 1,800,000,000 miles, which is the same as the distance of the planet Uranus from the sun. Though the light of the two stars combined is forty-eight times that of our own sun, their combined mass is only between three and four times the sun's mass, so low is their density. Procyon, at the northeastern vertex of the triangle, is another neighbor of the solar system, being only ten light years distant. It also is attended by a companion star.

The two combined radiate about six times as much light as our own sun, but are only one and one-third times more massive. Were our own sun as far from us as Procyon it would appear to be only one-sixth as bright as this first magnitude star. Ruddy Betelgeuse, the third star in the triangle, presents a strong contrast to the other two in every way.

It is in the first place so distant that it gives no measurable parallax. In comparison to Betel-

geuse, Sirius and Procyon are dwarfs. Like Rigel and Canopus, Betelgeuse is one of the supergiants of the universe. Though one of the stars in Orion it is not physically associated with the great constellation and its enveloping nebulosity. It is travelling in a different direction and simply chances to lie in such a position as to complete the quadrangle that roughly outlines the form of the warrior.

Betelgeuse is not only far more distant and far more luminous than Sirius and Procyon, but also radically different in its physical condition.

These three stars represent three distinctive types and three widely different stages of evolution. Sirius is a star of the hydrogen type, which is, in fact, sometimes referred to as the Sirian type after this illustrious member. Next to the helium stars, of which nearby Rigel, the brightest star in Orion, is an example, these hydrogen stars are the hottest of all the stars.

Their brilliant surfaces are not veiled by cooler enveloping layers of metallic vapors such as surround the photosphere of our own sun and stars still more advanced in type. Intense absorption

lines of hydrogen in the spectrum give them their characteristic name and prove that they are surrounded by glowing hydrogen gas.

The intense blue-white and white light of the helium and hydrogen stars respectively is an indication of their great heat, for the hotter a body the more intense are its radiations in the violet and ultra violet end of the spectrum.

As a body cools the maximum intensity of its radiations shifts toward the red end of the spectrum.

Fully half of all the stars so far examined have proved to be either helium or hydrogen stars. This may be due to the fact that these intensely brilliant stars may be seen to a far greater distance than less luminous stars.

Procyon stands between the hydrogen and solar stars in type, and more closely approaches our own sun in its physical condition. Strong lines of calcium are one of the most distinctive features of the spectra of such stars, though the hydrogen lines are still very conspicuous, as they are also in the spectrum of our own sun.

Stars such as Procyon are usually spoken of as calcium stars, owing to the prominence of the lines

of this element in their spectra. Other metallic lines also begin to appear faintly at this stage of evolution and such stars are slightly tinged with yellow as their atmospheres become charged with the vapors of the denser gases.

Compared to Sirius, Procyon is noticeably yellowish and this tinge is still further deepened in the solar stars to which our own sun belongs. Brilliant Capella, also visible at this time, due north of Betelgeuse and midway between it and the pole, is a typical solar type star in which the metallic lines so faint in Procyon have increased in strength until they equal the hydrogen lines in intensity. Such stars are decidedly cooler than the hydrogen and helium stars and the more deeply they are tinged with yellow the more are their atmospheres charged with the heavier metallic vapors.

A still later stage in the evolution of the stars is typified in the orange-colored star Aldebaran in the Hyades just to the northwest of Orion. In stars of this class the metallic lines have increased in strength until they have become stronger than the lines of hydrogen. The rays from the blue end of the spectrum have become absorbed more and more in an increasingly dense atmosphere and for

this reason such stars are reddish orange in appearance.

We now arrive after all these gradual changes at the type of the giant red star Betelgeuse that is so radically different from the types of the two stars Sirius and Procyon. Betelgeuse is an irregularly variable red star.

The majority of stars of this class are variable in their radiations for some reason not clearly understood. Any one observing this interesting red star from season to season will readily note its peculiar fluctuations of brightness.

At times it is only a shade brighter than Aldebaran, a convenient star with which to compare it. Again it will be equal in brightness to Rigel, diagonally opposite to it in the quadrilateral of stars.

The spectrum of Betelgeuse is that of a typical giant "M" star, as it is called astronomically. It is beautifully fluted in appearance, due to the presence of the compound known as titanium oxide. The presence of oxides in the atmosphere of a star indicates a decided drop of temperature, for no such compounds could exist unless the temperature were comparatively low. Why titanium oxide

should so completely dominate the spectra of such stars is one of the unsolved mysteries of the stars. It is also one of the compounds that appear in the spectra of the sun spots. The temperature of sun spots, it is well known, is decidedly below that of the surrounding solar surface. Only a few hundred stars of the same type as Betelgeuse are known and they are all believed to be at great distances and at least several thousand times more luminous than our own sun.

The cause of the irregular fluctuations of brightness of these stars is believed to lie within the stars themselves. No law or order in its workings can be detected as yet, however. Betelgeuse usually goes through its irregular variations of light, which amount to about half a magnitude at most, within a year or two.

There is, at the greatest, a change of more than forty per cent. in the intensity of the radiations of this star. Its sudden and unexpected increases of luminosity may possibly occur when its dense atmosphere of metallic vapors is temporarily rent by the pressure of pent-up forces within a highly heated interior. To live upon planets encircling such suns would appear to us extremely

hazardous and no more to be relished than existence near an active volcano.

An outburst of activity that would rapidly change the intensity of the radiations of such a star nearly fifty per cent. would have a most disastrous effect upon organisms with which we are familiar. And yet adaptations to conditions under the sway of such an erratic ruler might be such that the life process would continue there no more disturbed than it is on our own planet when passing clouds temporarily conceal the face of the sun.

CHAPTER XL

THE CONSTELLATIONS OF SPRING

IT IS not difficult to locate all the constellations for a certain season of the year if we once fix in our minds the positions of two or three of the more prominent groups. Let us consider first the two constellations known as Ursa Major, "The Great Bear," and Leo, "The Lion." Both are conspicuous in the spring, and we should have no trouble in locating them readily.

At nine o'clock on the first of April these two groups are almost directly on the meridian. A month later they, as well as all the other constellations, have apparently shifted about thirty degrees westward. The winter constellations have disappeared below the western horizon and the constellations that are overhead in summer evenings are now appearing on the eastern horizon. Taking

as our time of observation May first, about nine o'clock in the evening, we find in the north, just west of the meridian, the seven stars of the Big Dipper, or Great Bear, and south of it Leo facing westward.

The head of Leo is outlined by a sickle-shaped group of stars, six in all, with the bright, white star Regulus in the end of the handle. To the eastward we see the other stars that outline the body. Denebola, a star of the second magnitude, marks the tail and is about twenty-five degrees east of Regulus. With these reference points we can easily locate other conspicuous constellations. Southeast of Leo is Virgo, a large Y-shaped constellation, which contains the beautiful white star Spica, and again southeast from Virgo is the small constellation Libra, marked by four rather faint stars. To the southwest of Spica is a more conspicuous group of stars of the second and third magnitude in the form of a quadrilateral. This is the constellation Corvus, and just west of Corvus is the less conspicuous group known as Crater. In the southern skies we also have the long constellation of Hydra, which extends from a point a little southwest of Regulus, where a small group of faint stars mark the head,

to a point in the southeast, where the fiery Antares will soon rise in the constellation Scorpio. Hydra contains one second magnitude star known as Alphard or Cor Hydræ, standing very much alone. It is about twenty degrees south of Regulus and a little to the westward. This long, but rather faint constellation of Hydra extends nearly ninety degrees across the southern sky below Leo, Virgo, Crater, Corvus and Libra. Let us return now to the Great Bear, which, by the way, is a much more extensive constellation than the part which forms the Big Dipper, or the tail and body of Ursa Major. A considerable portion of the space south and east of the configuration known as the Big Dipper belongs to Ursa Major. It is occupied, however, by inconspicuous stars. On a line between the ena star in the handle of the Dipper and Denebola in Leo are situated two very interesting, though small, constellations; Canes Venatici, the more northerly one, is marked by two stars, the Hunting Dogs, with which Boötes the Herdsman is chasing the Great Bear around the pole. The northern of the two dogs is Asterion, the southern Chara. Between Denebola and Canes Venatici is the constellation, almost directly overhead at this time, known

as Coma Berenices. In this constellation, it is estimated, over a hundred nebulæ are gathered in a space no greater than that covered by the full moon. This little constellation also contains a great number of fifth and sixth magnitude stars and many interesting doubles. Canes Venatici also contains some fine doubles and a beautiful star cluster, as well as the noted "Whirlpool Nebula." Both constellations offer a fine field for the telescope.

If we now turn to the western sky we can trace out a bright arc of first and second magnitude stars beginning with Capella, the yellowish star in the northwest in the constellation Auriga. We can distinguish Capella also by the group of three stars about five degrees to the southwest, known as the "Kids." Following this arc from Capella southward we come first to Beta Aurigæ, then in order, Castor and Pollux in Gemini and finally Procyon in Canis Minor.

In the east we now see the large constellation of Hercules. Hercules contains no star of the first or second magnitude, but many of the third. It contains one of the finest star clusters in the heav-

ens, seen on a clear, dark night as a patch of white light. The telescope dissolves it into a magnificent cluster of over 5,000 stars. Northeast of Virgo and southeast of Ursa Major is the large constellation of Boötes, a kite-shaped configuration of stars whose principal star is the ruddy Arcturus. Almost overhead now is the conspicuous equilateral triangle formed by the three bright stars, Denebola in Leo, Spica in Virgo and Arcturus in Boötes. Once located in the heavens it will never be forgotten, and when we see it high in the heavens in the evening we know that spring has come once more. for it is known as the characteristic configuration of spring. Between Hercules and Boötes is the Northern Cross, a beautiful little semicircle of six small stars. It was in this constellation that the "blaze star," or Nova, of 1866 appeared. In the northeast is the small constellation of Lyra, identified at once by the brilliant blue-white star Vega. Directly east of Vega is the constellation Cygnus, known as the Northern Cross, now coming into view low in the northeast.

Boötes, Corona Borealis, Hercules, Lyra and Cygnus are all in a line across the heavens and Arc-

turus, in Boötes, Alphacca, the brightest star in Corona; Vega in Lyra and Deneb in Cygnus are on a diagonal line directed toward the northeast.

CHAPTER XLI

THE CONSTELLATIONS OF SUMMER

THE constellations that are most noticeable during the summer months are Scorpio in the south, Hercules and Corona Borealis directly overhead at nine o'clock the middle of July and Ophiuchus and Serpens between these two constellations and Scorpio.

In the northwest can be seen the Big Dipper, which never sets in our latitudes, but is best seen in the spring and summer months. In the fall and winter it appears to rest upon the horizon and is too low to be well seen. The head of Draco is now nearly on the meridian and just north of Hercules. It is marked by a group of four fairly bright stars, and from there the neck and body can be traced first eastward, then curving northward and bending sharply westward, so that the body lies

between the creature's head and the Little Dipper, and twines around between the two Dippers. The tip of the tail lies at the middle of the line between the Pointers and the Pole Star. The Pointers, we remember, are the two stars farthest from the handle of the Big Dipper that outline the outer edge and a line drawn through them and extended northward a distance about equal to the whole length of the Big Dipper brings us to the Pole Star, which is a second magnitude star at the end of the handle of the Little Dipper.

The Northern Cross, in Cygnus, is now conspicuous in the northeast. The brightest star, Deneb, or Arided, as it is better called, for there are several Denebs in different constellations, is situated at the northern end, or top, of the Cross and Albireo, the noted double at the bottom. Arided, or Deneb, lies in a line with Vega in Lyra, the next constellation west of Cygnus, Alphacca in Corona and Arcturus in Boötes, which is now west of the meridian.

Spica, in Virgo, sparkles brilliantly, low in the southwest. Vega still remains the most brilliant star visible, although ruddy Arcturus is of the same magnitude. We include in our list of bright stars Antares in Scorpio, which is on the meridian

well to the southward at this time, and Altair, in Aquila, a yellow star of the first magnitude, which is well up in the eastern sky. It is readily found from the fact that it is attended by two fainter stars exactly in line with it and at nearly equal distances on either side. In the constellation of Aquila, about twenty degrees southwest of Altair, appeared the brilliant Nova of 1918, known as Nova Aquilæ No. 3, since it was the third Nova to appear in this constellation. About fifteen degrees northeast of Aquila is the little diamond-shaped group of third magnitude stars, known as Delphinus and often called "Job's coffin."

Vega, as well as Altair, is accompanied by two fainter stars. They form a small equilateral triangle with it, whose sides are only two and one-half degrees long. A sahrp eye will detect the fact that Epsilon Lyræ, the northernmost of the two stars, is double, and a small telescope will show that the star is really quadruple, each of the two components of the wide double being also double. It is the finest example we have of a quadruple star. All four stars are physically connected and form one mighty system. Beta Lyræ, which lies about eight degrees southeast of Vega, is both a variable

and double star. In the short period of thirteen days its brightness fluctuates nearly a magnitude. Its change in brightness is due to the fact that it has a companion star that intercepts at times part of the light from the brighter star.

It requires considerable stretch of imagination to trace some of the mythical and legendary figures that have been mapped out in the heavens. It is rather difficult to see that Lyra is a harp or Hercules and Ophiuchus heroes performing wonderful feats with serpents. Boötes is a hunter pursuing the Great Bear around the Pole, accompanied by the two hounds, Canes Venatici, though according to some legends he is represented as a herdsman driving the seven plough oxen, the stars that form the Big Dipper. The giant Hercules stands with his foot on the head of Draco and his body is marked by a quadrilateral of four stars midway between Lyra and Corona Borealis, or the Northern Crown. The latter constellation is one of the few that really resembles the object for which it is named, as it consists of a nearly perfect semicircle of six stars. The brightest, Gamma or Alphacca, is the gem in the crown.

Alpha Hercules, which marks the head of Her-

cules, is a variable star which changes irregularly in brightness from the third to the fourth magnitude. It is also a beautiful orange and blue double. One can easily find it in connection with Alpha Ophiuchi, which is about six degrees east of it and which forms with Vega and Altair a nearly equilateral triangle. Alpha Hercules is the fainter of the two stars. The large constellations of Ophiuchus and Serpens lie west of Aquila and south of Hercules and Corona. The head of Serpens lies about ten degrees south of Corona Borealis and is marked by a group of small stars; from there a line of bright stars can be traced first to the southwest for a few degrees, then south and eastward almost to Aquila. Ophiuchus, the serpent bearer, is another mythological figure represented by a considerable number of fairly bright stars grouped in rather indefinite forms. The hero is represented with his feet on Scorpio and his head very close to Hercules, while he grasps Serpens with both hands. Scorpio is directly south of Ophiuchus. Fiery Antares marks the creature's heart and his tail is a long line of stars reaching nearly to the southern horizon. The constellation is of peculiar shape and easily recognized. The two bright stars in Libra,

the next constellation westward, marked the creature's claws according to some ancient maps, but there is considerable confusion as to the exact boundary between the two constellations. Antares is a most interesting object in the telescope, as it is a double star with a small green companion. As its name indicates it is the "Rival of Mars" and to the naked eye shows a strong resemblance to the ruddy planet.

Sagittarius is now visible in the southeast, its little inverted milk dipper outlined by five stars. A little southwest of the star in the end of the handle is a small triangle of stars, making a noticeable group of eight stars in all. Sagittarius and Scorpio mark one of the most interesting regions of the sky, as the Milky Way is particularly dense and bright here, and very peculiar in structure. According to the most recent researches it is in this general direction that the center of the sidereal universe is located.

CHAPTER XLII

THE CONSTELLATIONS OF AUTUMN

EACH season of the year brings its characteristic configuration of stars in the heavens. The magnificent constellation of Orion is always associated with winter months. The great triangle formed by Spica, Denebola and Arcturus appears in spring and early summer, while the Scorpion with red Antares glowing in its heart is seen in southern skies on midsummer nights. In Autumn we have the Great Square in Pegasus, visible in the east in September, overhead in October.

At nine o'clock the middle of September the Northern Cross of the constellation Cygnus is directly in the zenith, while Altair in Aquila is just west of the meridian. Altair can always be recognized by the two fainter stars that are in line with it at nearly equal distances on either side. Del-

phinus, the Dolphin, is a little diamond-shaped group of third magnitude stars commonly spoken of as Job's Coffin, that now can be found on the meridian south of Cygnus and about twenty degrees to the northeast of Altair. It contains a few other faint stars visible to the naked eye, in addition to those that form the diamond. Vega in Lyra is the most brilliant star visible and is just west of the meridian.

In western skies the extensive constellation of Hercules is still in view and south of it Ophiuchus and Serpens. Boötes and Scorpio are now at the western horizon and the Dipper is far over to the northwest.

Turning to the eastern half of the heavens, we cannot fail to discover the Great Square in Pegasus. It is best considered in connection with Andromeda, as the star in the northeast corner of the square does not belong to the constellation Pegasus, but is Alpha Andromedæ, one of the three stars in a curved line that belong to the constellation Andromeda, which is now in the northeast just south of the peculiar W-shaped group of stars that forms the constellation of Cassiopeia. An imaginary line drawn from Polaris, the Pole Star,

through the star in the W that is farthest west, known as Beta Cassiopeiæ, and extended as far again, brings us to Alpha Andromedæ in the corner of the Great Square. About fifteen degrees due west is Beta Pegasi, an irregularly variable star that marks the northwestern corner of the square. Near this star is a group of three fainter stars that also belong to the constellation Pegasus. The star that marks the southwestern corner is about fifteen degrees due south of Beta Pegasi, and is known as Markab. A line from Alpha Andromedæ drawn diagonally across the square to this star and extended as far again passes through the neck and head of the Winged Horse. His hindquarters are missing on star maps that show the mythological figures, but his forelegs are marked by four faint stars northwest of the square and just east of Cygnus. About fifteen degrees due south of Alpha Andromedæ is the second magnitude star that completes the Great Square. The entire constellation of Pegasus covers an extensive region in this portion of the heavens.

The Great Nebula in Andromeda, visible even to the naked eye, can be found about ten degrees northwest of the middle star in the line of three

stars that characterizes the constellation of Andromeda. It forms a little triangle with two faint stars near it.

Just east of the meridian at this time and above and west of the W-shaped group of stars in Cassiopeia is the constellation Cepheus, which contains very few bright stars. The remarkable variable star Delta Cephei, which changes more than a magnitude in brightness in about five days, is one of the stars in a little triangle that marks the king's head. Cepheus is represented as sitting behind his wife, Cassiopeia, with his feet on the tail of the Little Bear. Andromeda, the daughter, is represented with her head resting upon the shoulder of Pegasus, the winged horse, that brought Perseus to rescue her from Cetus, the sea monster, lying far to the south beyond the constellations Aries and Pisces. Perseus is the brilliant constellation just east of Andromeda crossed by the Milky Way.

The Milky Way is now a beautiful sight upon clear nights. It passes from Cassiopeia across the shoulder of Cepheus, through Cygnus in the zenith and thence divides into two branches, one passing through Aquila and Sagittarius, and the other

through Ophinchus to Scorpio. Near this point the two branches again meet.

Of the zodiacal constellations now visible Sagittarius is readily found in the southwest by its peculiar configuration of eight bright stars, five in the shape of a little dipper inverted toward the southern horizon and three forming a triangle southwest from the star at the end of the handle.

East of Sagittarius come in order the three zodiacal constellations, Capricornus, Aquarius, and Pisces. Capricornus, the sea goat, represented with the head and body of a goat and tail of a fish, has few bright stars. It contains, however, one of the few double stars visible to the naked eye, Alpha Capricorni.

A line drawn from Albireo at the bottom of the northern cross through Altair and extended about as far again, brings us to this double. Three degrees further south is Beta Capricorni, the brightest star in the constellation.

Aquarius, the water bearer, is east and north of Capricornus and southwest of Pegasus. The characteristic configuration of this constellation is the little Y of third and fourth magnitude stars about

20 degrees southwest of the square in Pegasus. This is supposed to represent the water jar from which Aquarius pours the stream of water outlined by many faint stars lying to the southwest and south. At the southern end of this stream is Piscis Austrinus, the Southern Fish, which contains one first magnitude star, Fomalhaut, just visible above the southern horizon at this time of year. It is in line with the western edge of the square in Pegasus, but fully 45 degrees south. Directly south of the Great Square in Pegasus is a little polygon of faint stars which marks the head of one of the two fish in the zodiacal constellation Pisces. A line of faint stars runs from here eastward to meet another line of stars extending in a northerly direction toward the constellation Andromeda. This second line of stars represents the second fish in the constellation, and contains no bright stars. Part of the large constellation of Cetus, the Whale, is directly south of Pisces and Beta Ceti, which stands entirely alone, is the brightest star in this part of the heavens. The Chaldeans called this region the Sea, and it is not strange, for we have here Cetus, the Whale, the two fish in Pisces and Pisces Aus-

trinus, the Southern Fish, as well as Aquarius, the Water Bearer, Capricornus, the Sea Goat, and Delphinus, the Dolphin, quite an aquatic collection!

CHAPTER XLIII

BRILLIANT STARS OF THE SOUTHERN HEMISPHERE

STAR gazers of northern lands often overlook the fact that some of the most brilliant and beautiful stars and finest nebulæ and star clusters in the heavens belong to the southern hemisphere and are not visible in our latitudes.

The brilliant first magnitude star Formalhaut that culminates in the zenith in thirty degrees south latitude comes about twenty degrees above our southern horizon in late summer and autumn months to give us a hint of the beauties of the southland, and if our view of the southern horizon is not obstructed by houses, trees or mountains, as is so often the case, we may then see this interesting star of the south. Stars are never seen at their best when near the horizon, however, for we then view them through denser layers of atmosphere

than if they were nearer the zenith. All celestial bodies shine brightest when they are overhead.

Magnificent blue-white Canopus, the second brightest star in the heavens, lies just below our southern horizon in the large and important southern constellation of Argo Navis, named for the famous ship of the Argonauts. It is usually divided into three constellations—Puppis, Carina and Vela. Canopus was the chief pilot of the Argonauts, but the star was known and worshipped on the banks of the Nile long before it received its name from the Greeks and it has been called the Star of Egypt. It has also been a guide to many tribes in Africa, South America and Australia in their journeys through pathless wilds.

Although Sirius appears nearly twice as brilliant as Canopus, this is due only to the fact that Sirius is comparatively near to us, not quite nine light years distant, while no accurate measurement of the distance of Canopus has yet been made. It is, as far as we know, the greatest of all the giant suns and its light-giving power has been estimated as high as fifty thousand times that of our own sun. Sirius, with a brilliancy estimated at forty-

eight times that of the sun, shrinks into a pygmy when compared with Canopus.

Other brilliant first magnitude stars in southern skies that are invisible to us are Alpha Centauri, the nearest of all the stars and one of the finest doubles in the heavens; Beta Centauri, a beautiful white star near Alpha—the two reminding us of the twins in Gemini; Achernar, far south in the river Eridanus, and the beautiful bluish-white double star, Alpha Crucis, the brightest of the four stars that form the Southern Cross.

The constellation of the Southern Cross is the most noted of all the southern constellations. It serves as a timepiece for the southern hemisphere, just as the Great Dipper does for northern lands. It stands in a nearly upright position when culminating or passing the meridian.

Early Spanish conquerors of Mexico and South America regarded this cross as a token of heaven's approval of their attempt to plant the Christian faith in the wilds of the New World. Upon the first maps of the southern hemisphere South America appeared as "Terre Sancte Crucis," the Land of the Holy Cross.

The southern constellations Argo Navis, Crux

and Centaurus, are all traversed by the Milky Way.

The galaxy in Argo Navis is crossed by many dark bars, and near the Southern Cross is the peculiar pear-shaped hole known as the Coal Sack. One of the most peculiar stars in the heavens is situated in southern skies and is invisible in our latitudes. This is Eta Argus, which lies in the midst of a nebula and possesses most unusual and irregular fluctuations of light which distinguish it from various classes of variable stars or temporary stars.

As far back as the year 1677 this star was observed to fluctuate in brightness. Between that date and 1800 records show a great range of brightness. In 1843 it became brighter than any other star except Sirius. At present it is barely visible to the naked eye. When at its brightest, in 1843, it gave 25,000 times the amount of light that it does now.

Far to the south in the circumpolar constellation Tucana is to be found the finest of all globular star clusters and in Argo Navis there is the finest irregular star cluster in the heavens. Two splendid globular star clusters, located in this large and

noted constellation, are visible even to the naked eye. In Argo we also find the largest and brightest of the naked eye nebulæ.

Of unusual interest in the southern hemisphere are the Lesser and Greater Magellanic Clouds. They look very much like small star clouds detached from the girdle of the galaxy which encircles the heavens.

The Magellanic Clouds are rich in nebulæ, variable stars and star clusters and the Greater Cloud has a decidedly spiral form. It has been suggested that our own stellar system, with its millions of stars, its galactic star clouds, its nebulæ, variable stars and star clusters would present very much the same appearance that the Greater Magellanic Cloud does to us if it were transported to a distance of a hundred thousand light years.

Those who travel to the southern hemisphere are impressed by the fact that no bright star marks the south pole of the heavens. To locate the north pole we have the bright second magnitude star, Polaris, at the end of the handle of the Little Dipper, and the two stars that outline the front of the bowl of the Big Dipper act as pointers to the pole star.

The seven stars of the Big Dipper are familiar to nearly every one in northern latitudes. As we pass southward the pole star sinks lower and lower toward the northern horizon, for its altitude above the horizon always equals the latitude of the observer. At the equator the north pole lies in the horizon, as does also the south pole. The belt of Orion crosses the meridian in the zenith. The view of the heavens from the tropics is probably unsurpassed, for we see from here the finest constellations of both hemispheres.

As we pass into the Southern Hemisphere the Big Dipper gradually sinks below the northern horizon and we turn our eyes toward the unfamiliar constellations surrounding the south pole, which rises higher and higher in the sky as we go southward. Canopus in Argo Navis, brilliant Achernar and the four stars of the Southern Cross now mount high into the heavens and the dearth of bright stars in the neighborhood of the south pole is very evident.

We miss the familiar Dippers of northern lands encircling the north pole of the heavens and find it hard to accustom ourselves to circumpolar regions so different. Toward the northern horizon we now

see the familiar star groups that passed through our zenith in middle northern latitudes, the Northern Cross, Lyra, and the Northern Crown, Boötes, Hercules, Perseus Andromeda and Pegasus ushering in the different seasons.

CHAPTER XLIV

THE ONE-HUNDRED INCH TELESCOPE OF THE MT. WILSON OBSERVATORY

THE 100-inch mirror for the greatest reflecting telescope in the world arrived safely at the summit of Mount Wilson, Cal., 5,700 feet above sea level, in July, 1917.

The new reflector has a light gathering power three times as great as that of the five-foot reflector of the Mt. Wilson Observatory, which shows stars as faint as the twentieth magnitude. It will, therefore, show stars one magnitude fainter.

It is estimated that fully one hundred million additional faint stars are within reach of this great reflector. Some of these stars may be comparatively near to us, their feeble luminosity being due to the fact that they are dwarf suns; others may be faint only because they lie on the outskirts of the uni-

verse. In actual luminosity such stars would equal or surpass our own sun.

Next to the 100-inch reflector in size comes the 72-inch reflector of the Dominion Astrophysical Observatory which started on its observing career in the spring of 1918. The greatest refractor is the 40-inch telescope of the Yerkes Observatory. Reflecting and refracting telescopes differ radically in their treatment of the light received from the stars. In a refractor the rays of light pass through the lens at the upper end of the telescope tube and travel down the tube, coming to a focus at a point within. They are then examined by the observer by means of the eye-piece at the lower end of the telescope tube. In the reflecting type of telescope the mirror is placed at the lower end of the tube and reflects the incident ray back through the tube to a secondary mirror placed so as to receive it before it reaches a focus and to reflect it in turn to the observer or photographic plate placed at one side.

It is possible to make reflectors much larger than refractors, since it is not essential that the glass be absolutely pure. In a reflecting telescope the function of the mirror is merely to act

as a support for a thin silver coating which is deposited upon its upper concaved surface. Twice a year this silver coating must be renewed. Arrangements have been made to have this quickly and easily done in case of the new reflector. The mirror will be removed by means of an electric elevator to the resilvering room in the same building. Since light does not penetrate the mirror, but is reflected from its highly polished surface to a secondary mirror and thence to the photographic plate or eye of the observer, it is not necessary that the glass entering into its composition have the high degree of perfection essential to the lens of a refracting telescope. The reflector is unsurpassed for photographic or spectroscopic work inasmuch as the quality of the light received is unchanged. In a refracting telescope the rays are always to some extent broken by passage through the lens. Perfect achromatism is the strongest point in favor of the reflector.

The field of good definition for the great reflector is small, however, only equalling in area one-half the disk of the moon. This is a restriction placed by the necessity for rapid photographic action.

Work upon the great reflector began in 1906,

when the St. Gobain glass works in France undertook to manufacture a block of glass large enough and perfect enough for a telescope of this size. After many attempts covering an interval of three years a satisfactory piece of glass for the great mirror was finally obtained and delivered at the optical shops of the Mount Wilson Observatory in Pasadena, Cal., twelve miles from the summit of Mount Wilson.

Here for seven years it was to undergo a long process of grinding, polishing and figuring. All of this work was done by Prof. George Ritchey, a member of the staff of the observatory. In its finished condition the mirror weighs four and a half tons and is nearly thirteen inches in thickness. This thickness is essential to prevent the mirror bending of its own weight. It has been subjected to many tests, increasing in refinement as the work progressed, and is now considered to be practically perfect.

On July 1, 1917, it was packed in an octagonal shaped box lined with paraffin to keep out the dust and taken up the narrow winding mountain road six miles in length on a truck geared to a maximum speed of two miles an hour. Another truck pre-

ceded it, also a gang of workmen with tools to repair any defect in the road. The great sections of the casting were made at the Fore River Shipyards at Quincy, Mass., and shipped around Cape Horn, because they were refused as shipments by railroads, being too wide for flat cars and too high for tunnels. All parts of the great instrument that were not of unusual size and that required careful workmanship were designed and made at the instrument shops of the observatory in Pasadena.

The instrument is housed in a steel building with a 100-foot dome weighing 500 tons that revolves easily and rapidly by means of electrical appliances. The moving parts of the great reflector, which weigh about 100 tons, are also electrically controlled. Every detail upon which the successful operation of the huge instrument depends has been carefully worked out by opticians and instrument makers connected with the observatory.

The problems that the new instrument will assist in solving will be chiefly of an astrophysical nature in keeping with the lines of research undertaken by this observatory, such as the form and extent of the universe, the nature of star clusters and nebulæ, the origin and evolution of stars and their

physical properties, streaming tendencies and velocities. Most of all this work will be done by means of photographic and spectroscopic attachments and not by direct observations.

At the present time special attention is being given to the red stars as bearing upon the question of the scattering of light in space. It has been observed that among stars fainter than the eighteenth magnitude there are few, if any, whiter than our own sun, which is classed as a yellow star, although faint white stars are present in the star clouds of the Milky Way.

This preponderance of red stars among the faint stars, which are on the whole the most distant, has led to the belief that minute particles of matter, cosmic dust, may scatter the light of distant stars and give them a red tinge, just as the rays of the setting sun have a reddish tinge due to their passage through the dense, low-lying strata of the atmosphere. It is known, on the other hand, that stars also acquire a reddish tinge with advancing age and a lower temperature, and also that as a star advances in age its velocity increases, and so the question arises whether these faint stars may not be reddish because they are advanced in

type, and distant, because they have travelled far. It is one of the questions that the new instrument is well qualified to attack, since it is particularly adapted to a study of faint, distant stars.

It is also peculiarly fitted to investigate the mysterious spiral nebulæ, especially the smaller members of the class. Are they "island universes," faint because of great distance, or do they represent the first stages in the birth of star systems comparatively near and small? There are spirals of all degrees and magnitudes, from the Great Spiral in Andromeda, visible to the naked eye, to the faintest specks of spiral form visible in the large telescopes. What will the great reflectors have to tell of these wonderful formations?

The feelings of the explorer must come to those first privileged to guide this mighty instrument and penetrate into regions of space hitherto unexplored. Man stands upon his tiny planet, which is but an atom in the universe, and tries to extend his vision further and further into the eternity of life that flows in a ceaseless cycle of change before his eyes. Very slowly and laboriously and heavily handicapped he tries to solve, step by step, the mighty riddle of creation.

One more step forward will be taken when this noble instrument is turned toward the heavens and those who have labored long and tirelessly to make it worthy of its task begin to gather the precious fruits of their labors.